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ABSTRACT

A programmed instruction course was developed, consisting of fifteen experiments encompassing eleven separate pieces of equipment operational in a solar and energy conservation lab. The programmed instruction manual for the lab was evaluated and revised during a workshop. This evaluation indicated that both the lab and manual are valuable tools aiding in efforts to conserve fossil fuels. The manual, which is also provided, consists of nine sections and an appendix. The first two sections contain programmed experiments involving a solar cycle trainer and solar schematic trainer. Section 3 provides power solar trainer instructor and trainee manual materials. Section 4, which deals with a heat pipe, contains general characteristics of the heat pipe, a simplified theoretical analysis, an introduction to a heat pipe mini-lab, and suggested experiments for the mini-lab. Computer programs dealing with the cooling and heating modes of a solar-assisted heat pump and an air-to-air solar trainer are contained in sections 5-7. Section 8, which deals with heat pump technology, contains a review of the simulated system and two practice exercises. Section 9 presents a sample print-out covering a domestic solar hot water heater. An appendix discusses teaching the principles of solar energy in the undergraduate engineering laboratory. (MN)

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Final Report

Programmed Instruction Manual for a New Solar and Energy Conservation Laboratory

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EDUCATION & WELFARE
NATIONAL INSTITUTE OF
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Agriculture & Technical College
Farmingdale, New York
Division of Engineering Technologies
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CE 026 990

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FINAL EVALUATION REPORT

October 6, 1978

VEA GRANT NO. 464-36B 78-36-794

PROGRAMMED INSTRUCTION MANUAL

FOR A NEW SOLAR AND ENERGY CONSERVATION LABORATORY

The design, construction and installation of our Solar and Energy Conservation Lab took place simultaneously with the programmed course development needed to implement its educational objectives. Fifteen experiments encompassing the eleven separate pieces of equipment that constitute this new lab have been outlined. A ten to fifteen session workshop under the aegis of our Continuing Education Program is being planned to test the effectiveness of the new lab course and its equipment. The Programmed Instruction Manual for the lab will be evaluated and revised during the course of this workshop, after which a final copy will be issued.

The details relating to the above may be subdivided as follows:

1. Description of Equipment and the number of experiments to be run for each set up:

ITEM	DESCRIPTION OF EQUIPMENT	NO. OF EXP.
(a)	Heat Pipe	1
(b)	Solar Service Trainer	1
(c)	Solar Cycle Trainer	1
(d)	Solar Schematic Device	1
(e)	Reverse Cycle Demonstrator	1
(f)	Heat Pump Service Trainer	2
(g)	Solar Assisted Heat Pump	3
(h)	Air/Air Solar Simulator	1
(i)	Domestic Hot Water Solar Heater	2
(j)	Enthalpy Control Conservation Device	1
(k)	Integrated Solar Collector and Storage Device	1

2. The "Computer-Aided Lab Experiment," a new concept in programmed learning.

   (a) All observed data will be processed by a graphic computer which will be programmed to print-out calculated performance curves and tabulations that express the energy conservation relationships uncovered by the tests.

(b) In the case of the Domestic Hot Water Solar Heater, the computer will automatically monitor, scan, control and print out a daily report.

(c) In both of the above cases, the computer will prompt the user, in interactive mode, to supply the required data in the necessary logical sequence. Typical data, and a print-out of the energy relationships involved are provided at the end of this report for the Solar Assisted Heat Pump, in both heating and cooling modes.

3. Problems and difficulties get to be overcome

(a) The funds for the interface between the computer and the instruments monitoring the Domestic Hot Water Solar Heater are provided from the Technology Division's budget. Although the order for this equipment was placed in July, 1978, it is estimated that the earliest we can expect to receive it is about the beginning of January, 1979.

(b) The shipment of the Solar Service Trainer and the Solar Schematic Device has been delayed until the end of November.

(c) Revisions based on the student's operation of the computer programs are anticipated.

(d) All of the above will delay the publication of the final, student-tested Programmed Instruction Manual until late Spring, 1979.

4. Student Population Served

As a result of the intervention of the computer, the content of our lab instructional program should be understandable and of value, to both technicians and engineers.

5. Contribution to the National Interest

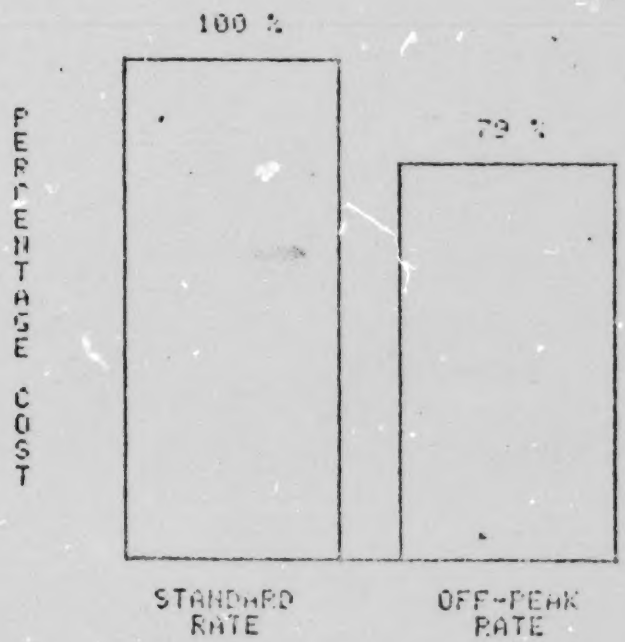
It is expected that the philosopy incorporated into the lab described above will provide our students with a more realistic and sophisticated understanding of the energy relationships we face today. This will be accomplished by virtue of our being able to incorporate the unavoidable complexities of the solar field into the computer programs, rather than burden each student with the mathematics and physics involved in the multitude of calculations required.

In conclusion, all of the computer programming and test runs of our new lab equipment and procedures point to our having created a valuable new tool in our efforts to conserve fossil fuels. The community has already begun to show an active interest in our project. Nassau BOCES (see attached letter) and the Long Island Chapter of ASHRAE are both scheduled to tour our new facilities in early Spring, 1979.

SOLAR ASSISTED HEAT PUMP - COOLING TEST
****

WATER FLOW RATE,(lbs/hr).	M5 = 200
COLD TANK CAPACITY,(lbs).	M6 = 0.0
ENTERING COIL TEMP.(F).	T5 = 0
LEAVING COIL TEMP,(F).	T6 = 50
INITIAL TANK TEMP.(F).	T7 = 40
FINAL TANK TEMP.(F).	T8 = 2[illegible]
DURATION OF TEST,(hrs).	H5 = 3
HEAT PUMP WATTS.	W5 = [illegible]
WATER PUMP WATTS.	W2 = [illegible]
FAN WATTS.	W3 = 36
PEAK RATE,($/KW-HR),	P7 = .10
OFF-PEAK RATE,($/KW-HR).	P8 = .0[illegible]
STANDARD RATE,($/KW-HR).	P9 = .05

COST COMPARISON OF COOLING SYSTEM USING OFF-PEAK ELECTRICAL RATE FOR 8-HOURS, PLUS STORAGE, VS. STANDARD ELECTRICAL RATE FOR 24-HOURS, WITHOUT STORAGE



Note : EER (Energy Efficiency Ratio) is : 10.4 for either type of operation

NASSAU COUNTY

BOARD OF COOPERATIVE EDUCATIONAL SERVICES
OF NASSAU COUNTY
DIVISION OF OCCUPATIONAL EDUCATION

September 29, 1978

Professor Taub
Air Conditioning Technology Department
State University at Farmingdale
Farmingdale, New York 11735

Dear Professor Taub:

I would like to know if it will be possible within the next few months to set up a field trip for my 2nd year Refrigeration & Air Conditioning students.

Two of my last year students, John Drexler and David Losak, dropped by our school and I asked them to give a brief presentation of the Air Conditioning Course at Farmingdale. Many of our 2nd year students are interested in going to Farmingdale, when they graduate this year.

We would also like to visit your Solar Energy Projects.

Hoping to hear from you at your earliest convenience.

Sincerely,

Paul Constas

Paul Constas, Instructor
Refrigeration & Air Conditioning

PC:mn
Encl.

P.S. Looking forward to seeing you again at the next Advisory Board Meeting.

SOUTHWEST CENTER
73 East Merrick Road, Freeport, New York 11520 • 516-868-7900
10 Henry Street, Freeport, New York 11520

Oct 9

October 6, 1978

Mr. Paul Constas
Refrigeration & Air Conditioning
BOCES Southwest Center
73 East Merrick Road
Freeport, New York 11520

Dear Mr. Constas:

Thank you for your letter of September 29, 1978. I will be very happy to welcome your second year Refrigeration and Air Conditioning students to tour our facilities.

We expect to have our Solar Lab completed by the end of January, 1979, and, therefore, I think the best time for your visit would be during the spring semester. I will be off each Friday that semester and would be available to spend any part of the day with you and your students.

We look forward to meeting with you.

Very truly yours,

Leon J. Taub
Associate Professor
Department of Air Conditioning

LJT:rdr

INSTRUCTIONAL MANUAL
FOR
SOLAR & ENERGY CONSERVATION
LABORATORY

INSTRUCTIONAL MANUAL
FOR
SOLAR & ENERGY CONSERVATION
LABORATORY

Prepared in connection with
VEA Project No. 7820341PS

SOLAR CYCLE TRAINER

PROGRAMMED EXPERIMENT I - SOLAR CYCLE TRAINER

STEP SEQUENCE	EXPLANATION
Step 1 Initialize Program by depressing Switches 2, 3, 5, 7, 11	All systems are non-operative
Step 2 Depress Switch 4 ... Sun	The outdoor temperature is 70°F. The sun is shining. There is warm water (80°F) in storage. With this set of conditions solar heat energy from the collectors is directed to the storage tank. SEQUENCE: Pump P1 circulates heated fluid through the collector piping loop. Pump P2 circulates heated fluid through the heat exchanger to the storage tank.
Step 3 Depress Switch 6 ... Storage 170°F	Temperature in the storage tank has reached at least 170°F. Since there is no call for heat from the thermostat, and the storage tank temperature is above 170°F, the purge unit is used to rid the system of excess solar energy. SEQUENCE: Pump P1 circulates fluid through the collector piping loop and the purge coil. Pump P2 circulates fluid through the heat exchanger to the storage tank.

PROGRAMMED EXPERIMENT 1 - SOLAR CYCLE TRAINER

STEP SEQUENCE	EXPLANATION
Step 4 Depress Switch 3 .., No Sun	Because of darkness or cloud cover, direct solar energy is no longer available. The system is static and the storage tank water is at 170°F.
Step 5 Depress Switch 14 ... Water Use	When there is a demand for hot water, heat will be taken from the storage tank to pre-heat inlet water to the conventional water heater.
Step 6 Depress Switch 5 ... Storage 80°F or Below.	Over a period of time, the demand for hot water will cause the temperature in the storage tank to drop to 80°F. At some point during this period the water heater element turns on. (This is determined by the set point of the water heater.)
Step 7 Depress Switch 4 ... Sun	Solar energy from the collectors is once again available and is used to supply heat to the storage tank. Since the water temperature in the storage tank has not reached 170°F, the element for the water heater is in operation. At this moment it is possible that both storage tank water and the water heater will be used in heating domestic hot water. SEQUENCE: Pump P1 circulates heated fluid through the collector piping loop. Pump P2 circulates heated fluid through the heat exchanger to the storage tank.

PROGRAMMED EXPERIMENT 1 - SOLAR CYCLE TRAINER

STEP SEQUENCE	EXPLANATION
Step 8 Depress Switch 8 ... Outdoor Temperature 45°F.	As the temperature drops below the set point of the thermostat, first stage heating is energized. Solar energy from the collectors is directed to the solar heat coil. This heat is then distributed throughout the home. SEQUENCE. Fluid is circulated through the collector piping loop. Fluid is also circulated through the heat exchanger to the solar heat coil.

PROGRAMMED EXPERIMENT 1 - SOLAR CYCLE TRAINER

STEP SEQUENCE	EXPLANATION
Step 9 Depress Switch 3 ... No Sun	When there is no solar energy available either in storage or directly from the sun, the system switches to auxiliary heat for space heating and hot water heating. SEQUENCE. In this mode the first stage of the thermostat pulled in, but there was no solar heat available to satisfy the heat demand. Auxiliary heat is then operated from the first stage of the thermostat.
Step 10 Depress Switch 13 ... No Water Use	There is no longer a demand for hot water. Only auxiliary heat for space heating is being used.

PROGRAMMED EXPERIMENT I - SOLAR CYCLE TRAINER

STEP SEQUENCE	EXPLANATION
Step 11 Depress Switch 4 ... Sun	When there is a first stage call for heat and solar energy is available from the collectors, it is directed through the solar heating coil. SEQUENCE. Fluid is circulated through the collector piping loop. Fluid is also circulated through the heat exchanger to the solar heat coil.
Step 12 Depress Switch 7 ... Outdoor Temperature 70°F.	If the temperature rises above the set point of the thermostat, solar energy is directed to storage. SEQUENCE. Pump P1 circulates heated fluid through the collector piping loop. Pump P2 circulates heated fluid through the heat exchanger to the storage tank.

PORGRAMMED EXPERIMENT 1 - SOLAR CYCLE TRAINER

STEP SEQUENCE	EXPLANATION
Step 13 Depress Switch 6 ... Storage, 170°F	When the storage tank has reached a temperature above 170°F, the system goes into purge to dissipate the excess solar energy. SEQUENCE. Pump P1 circulates fluid through the collector piping loop and the purge coil. Pump P2 circulates fluid through the heat exchanger to the storage tank.

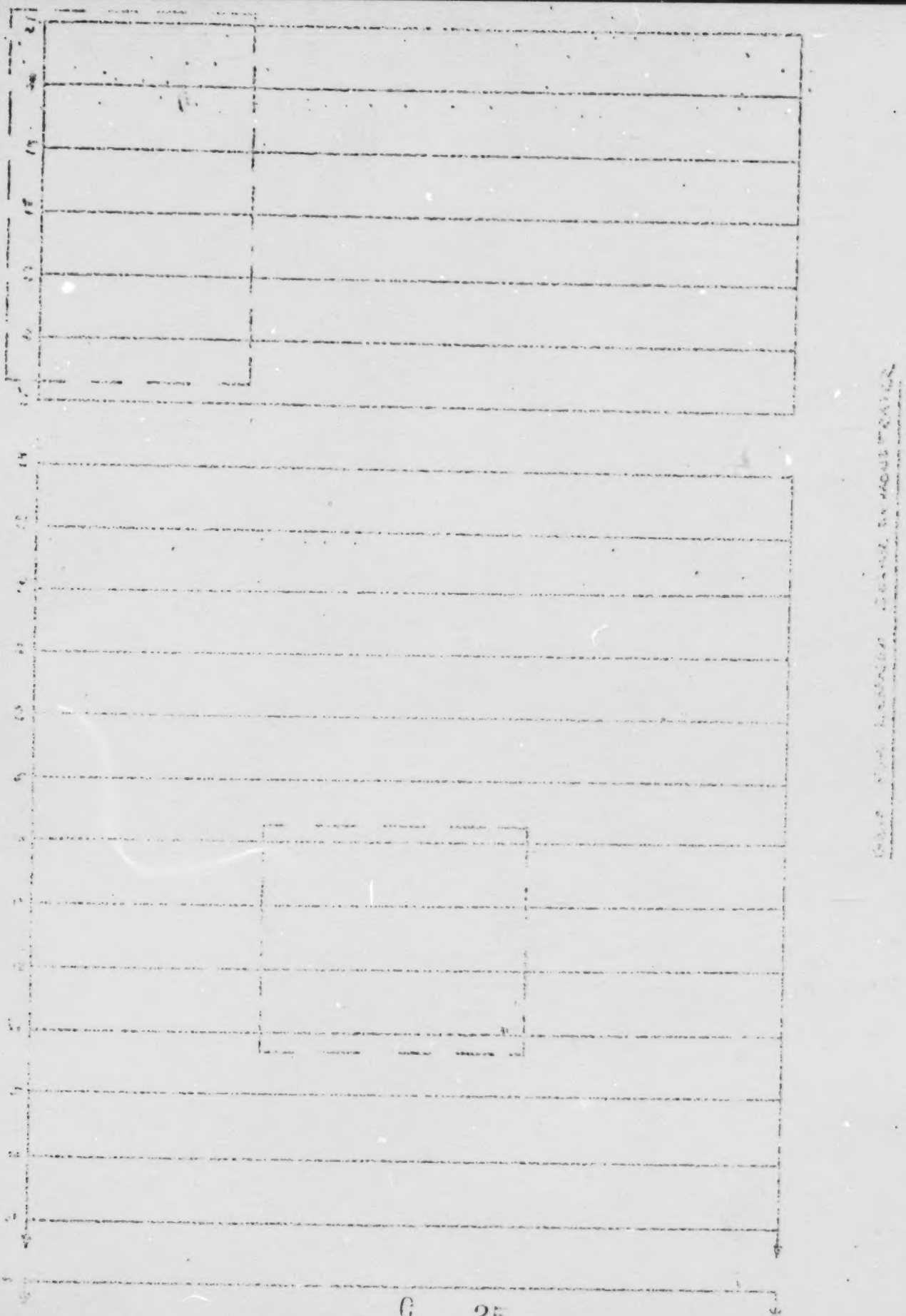
STEP SEQUENCE	EXPLANATION
Step 14 Depress Switch 8 ... Outdoor Temperature 45°F.	When the outdoor temperature drops, the room temperature again drops below the set point of the thermostat. The system switches from the purge cycle and delivers energy directly to the solar heating coil. SEQUENCE: Fluid is circulated through the collector piping loop. Fluid is also circulated through the heat exchanger to the solar heat coil.

STEP SEQUENCE	EXPLANATION
Step 15 Depress Switch 3 ... No Sun	If the sun is not available to create energy, the system switches and takes energy from the storage tank and delivers it to the solar heating coil. SEQUENCE: Fluid is pumped from the storage tank through the de-energized valve V2 to the solar heat coil.

STEP SEQUENCE	EXPLANATION
Step 16 Depress Switch 9 ... Outdoor Temperature 20°F.	As the temperature continues to drop, the solar heating coil cannot maintain the temperature level desired in the living space. This brings on the second stage auxiliary heat. In a real system the auxiliary heat will cycle on and off as needed. SEQUENCE: Fluid is pumped from the storage tank through the de-energized valve V2 to the solar heat coil. Auxiliary heat is also used.

STEP SEQUENCE	EXPLANATION
Step 17 Depress Switch 5 ... Storage, 80°F or below	When the temperature of the storage tank water drops to 80°F, auxiliary heat is switched to the first stage (first bulb) of the thermostat. SEQUENCE: In this mode the first stage of the thermostat pulled in, but there was no solar heat available to satisfy the heat demand. Auxiliary heat is then operated from the first stage of the thermostat.
Step 18 Depress Switch 4 ... Sun	When the sun is available for heating, the system will go back to a two-stage operation using heat from the collectors and the auxiliary heat. Auxiliary heat has now switched back to the second stage heat bulb. SEQUENCE: The system is operating on first stage heat demand. Energy is being supplied by collectors. Solar heating cannot handle heating load so second stage pulls in auxiliary heat.

STEP SEQUENCE	EXPLANATION
Step 19 Depress Switch 8 ... Outdoor Temperature 45°F	As the outdoor temperature moderates, the solar system is able to maintain the desired indoor temperature level without the use of auxiliary heat. SEQUENCE: Fluid is circulated through the collector piping loop. Fluid is also circulating through the heat exchanger to the solar heat coil.
Step 20 Depress Switch 12 ... Closed Solar Coil Limit	Excessive temperatures across the solar causes the solar coil limit to close. Fluid flow is routed to the storage tank.
Step 21 Depress Switch 11 ... Open Solar Coil Limit	Temperature across solar coil drops. The solar coil limit opens. Fluid again flows through solar coil.
Step 22 Depress Switch 10 ... Outdoor Temperature 95°F	When the temperature rises above 70°F the thermostat calls for cooling. Fluid is routed from the collectors to storage. SEQUENCE: The air conditioning system is operating.



SOLAR SCHEMATIC TRAINER

PROGRAMMED EXPERIMENT II - SOLAR SCHEMATIC TRAINER

STEP SEQUENCE	EXPLANATION
Step 1 Initialize Program by depressing Switches 2, 3, 5, 7, 11	All systems are non-operative
Step 2 Depress Switch 4 ... Sun	CONTROL SEQUENCE. The 3K differential control senses that the collector temperature is at least 18°F higher than the storage tank temperature and is energized. A. 3K1 contacts close. The circuit to pumps P1 and P2 is complete. B. 3K5 contacts close. The circuit to V2 valve is energized. C. 3K2 contacts open. The circuit is not complete.
Step 3 Depress Switch 6 ... Storage 170°F	CONTROL SEQUENCE. A. There is no heat demand from the thermostat. B. The 3K differential control senses that the collector temperature is at least 18°F higher than the storage tank temperature and is energized. 1. 3K5 contacts close. The circuit to valve V2 is complete. 2. 3K1 contacts close. Circuit to P1 and P2 pumps is complete. 3. 3K2 contacts open. Circuit to gas valve is not complete. NOTE: The system has been taking heat from the collector and putting it into storage. As the storage gets warmer there is less heat transfer through the heat exchanger. As this occurs heat begins to build up in the collector fluid C. 5K aquastat senses collector fluid temperatures above 200°F. This causes 5K1 contacts to close. The circuit to V1 valve is complete.

PROGRAMMED EXPERIMENT II - SOLAR SCHEMATIC TRAINER

STEP SEQUENCE	EXPLANATION
Step 4 Depress Switch 3 ... No Sun	CONTROL SEQUENCE. Because of static condition of the system no electrical circuits are energized.
Step 5 Depress Switch 14 ... Water Use	CONTROL SEQUENCE. No electrical circuits energized for hot water demand.
Step 6 Depress Switch 5 ... Storage 80°F or Below.	CONTROL SEQUENCE. No electrical circuits energized for hot water demand.
Step 7 Depress Switch 4 ... Sun	CONTROL SEQUENCE. A. The 3K differential control senses that the collector temperature is at least 18°F higher than the storage tank temperature and is energized. 1. 3K1 contacts close. The circuit to pumps P1 and P2 is complete. 2. 3K5 contacts close. The circuit to V2 valve is energized. 3. 3K2 contacts open. The circuit is not complete.

PROGRAMMED EXPERIMENT 11 - SOLAR SCHEMATIC TRAINER

STEP SEQUENCE	EXPLANATION
Step 8 Depress Switch 8 ... Outdoor Temperature 45°F.	CONTROL SEQUENCE. A. When the thermostat senses a demand for heat, it first closes the first stage contacts. This energizes the 1K relay coil through terminal "W1." 1. 1K5 contacts close. The circuit is complete to the furnace blower motor. 2. 1K2 contacts close. The circuit to the gas valve is not complete. 3. 1K4 contacts open. The circuit to valve V2 is not complete. 4. 1K1 open and closed contacts are reversed. This bypasses the storage sensor and places a resistor in the circuit. The collector sensor now controls the 3K relay. If the collector temperature is over 110°F the 3K relay is energized. If the collector temperature is under 110°F the relay is de-energized. B. Since the collector temperature is over 110°F, 3K relay energizes. 1. 3K5 contacts close. The circuit to valve V2 is not complete. 2. 3K2 contacts open. The circuit to the gas valve is not complete. 3. 3K1 contacts close, completing a circuit to pumps P1 and P2.

PROGRAMMED EXPERIMENT II - SOLAR SCHEMATIC TRAINER

STEP SEQUENCE	EXPLANATION
Step 9 Depress Switch 3 ... No Sun	CONTROL SEQUENCE. A. When the thermostat senses a demand for heat, it first closes the first stage contacts. This energizes the 1K relay coil through terminal "W1." 1. 1K5 contacts close. The circuit to the furnace blower motor is complete. 2. 1K2 contacts close. The circuit to the gas valve is complete. 3. 1K4 contacts open. The circuit to valve V2 is not complete. 4. 1K1 open and closed contacts are reversed. This bypasses the storage sensor and places a resistor in the circuit. The collector sensor now controls the 3K relay. If the collector temperature is over 110°F the 3K relay is energized. If the collector temperature is under 110°F the relay is de-energized. B. Since the collector temperature is under 110°F, 3K relay is de-energized.
Step 10 Depress Switch 13 ... No Water Use	CONTROL SEQUENCE. No solar electrical circuits energized when only heating with auxillary furnace.

PROGRAMMED EXPERIMENT 11 - SOLAR SCHEMATIC TRAINER

STEP SEQUENCE	EXPLANATION
Step 11 Depress Switch 4 ... Sun	CONTROL SEQUENCE. A. When the thermostat senses a demand for heat, it first closes the first stage contacts. This energizes the 1K relay coil through terminal "W1." 1. 1K5 contacts close. The circuit is complete to the furnace blower motor. 2. 1K2 contacts close. The circuit to the gas valve is not complete. 3. 1K4 contacts open. The circuit to valve V2 is not complete. 4. 1K1 open and closed contacts are reversed. This bypasses the storage sensor and places a resistor in the circuit. The collector sensor now controls the 3K relay. If the collector temperature is over 110°F the 3K relay is energized. If the collector temperature is under 110°F the relay is de-energized. B. Since the collector temperature is over 110°F, 3K relay energizes. 1. 3K5 contacts close. The circuit to valve V2 is not complete. 2. 3K2 contacts open. The circuit to the gas valve is not complete. 3. 3K1 contacts close, completing a circuit to pumps P1 and P2.
Step 12 Depress Switch 7 ... Outdoor Temperature 70°F.	CONTROL SEQUENCE. The 3K differential control senses that the collector temperature is at least 18°F higher than the storage tank temperature and is energized. 1. 3K1 contacts close. The circuit to pumps P1 and P2 is complete. 2. 3K5 contacts close. The circuit to V2 valve is energized. 3. 3K2 contacts open. The circuit is not complete.

PROGRAMMED EXPERIMENT 11 - SOLAR SCHEMATIC TRAINER

STEP SEQUENCE	EXPLANATION
Step 13 Depress Switch 6 ... Storage, 170°F.	CONTROL SEQUENCE. A. There is no heat demand from the thermostat. B. The 3K differential control senses that the collector temperature is at least 18°F higher than the storage tank temperature and is energized. 1. 3K5 contacts close. The circuit to valve V2 is complete. 2. 3K1 contacts close. The circuit to P1 and P2 pumps is complete. 3. 3K2 contacts open. The circuit to gas valve is not complete. NOTE: The system has been taking heat from the collector and putting it into storage. As the storage gets warmer there is less heat transfer through the heat exchanger. As this occurs, heat begins to build up in the collector fluid. C. 5K aquastat senses collector fluid temperatures above 200°F. This causes 5K1 contacts to close. The circuit to V1 valve is complete.

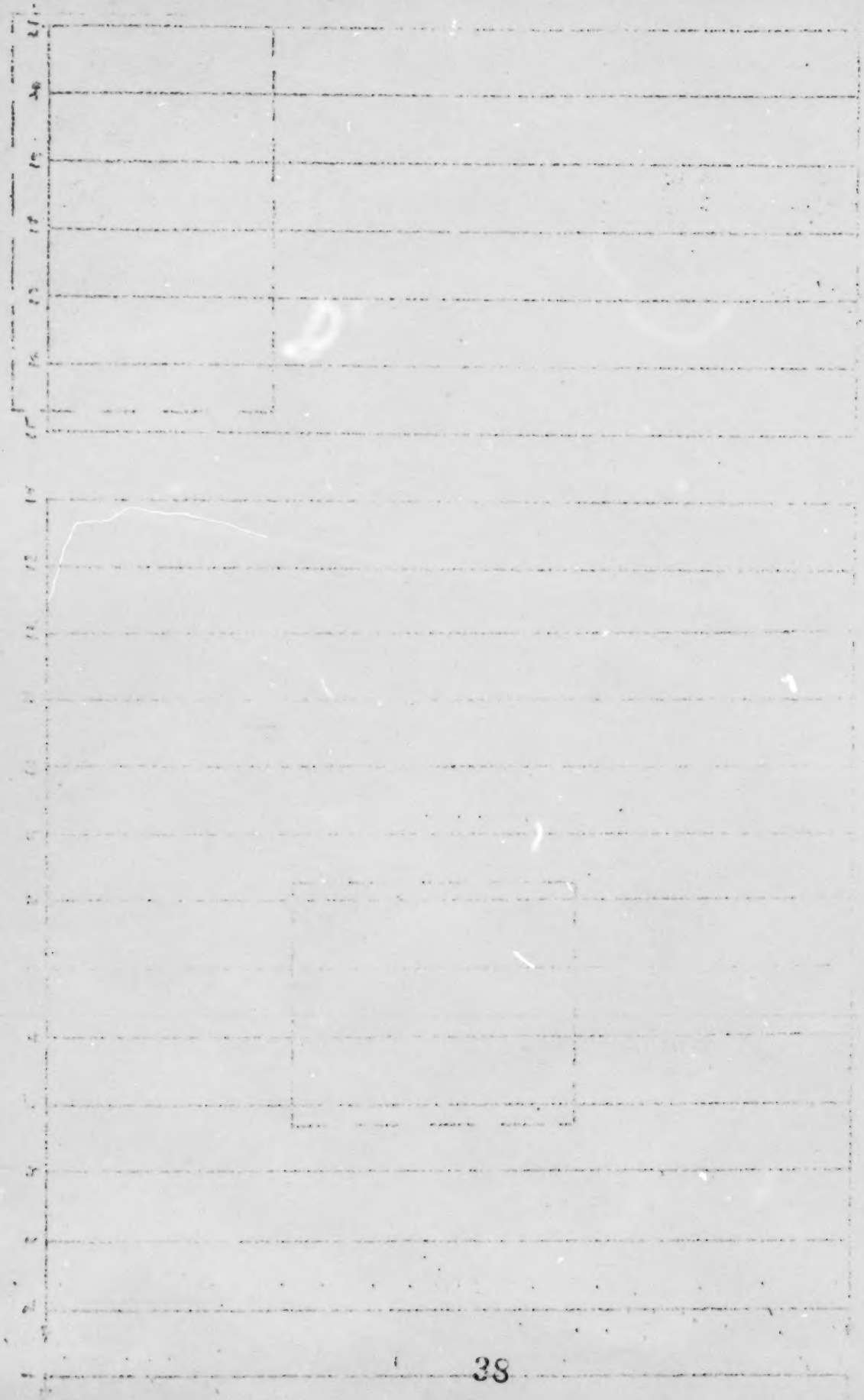
STEP SEQUENCE	EXPLANATION
Step 14 Depress Switch 8 ... Outdoor Temperature 45°F.	CONTROL SEQUENCE. A. When the thermostat senses a demand for heat, it first closes the first stage contacts. This energizes the 1K relay coil through terminal "W1." 1. 1K5 contacts close. The circuit is complete to the furnace blower motor. 2. 1K2 contacts close. The circuit to the gas valve is not complete. 3. 1K4 contacts open. The circuit to valve V2 is not complete. 4. 1K1 open and closed contacts are reversed. This bypasses the storage sensor and places a resistor in the circuit. The collector sensor now controls the 3K relay. If the collector temperature is over 110°F the 3K relay is energized. If the collector temperature is under 110°F the relay is de-energized. B. Since the collector temperature is over 110°F, 3K relay energizes. 1. 3K5 contacts close. The circuit to valve V2 is not complete. 2. 3K2 contacts open. The circuit to the gas valve is not complete. 3. 3K1 contacts close, completing a circuit to pumps P1 and P2.

STEP SEQUENCE	EXPLANATION
Step 15 Depress Switch 3 ... No Sun	CONTROL SEQUENCE. NOTE: In this mode the 4K aquastat senses storage temperature above 90°F. 4K is switched. 4K1 open and closed contacts are reversed. The circuit to 2K relay coil is not complete. A. When the thermostat senses a demand for heat, it first closes the first stage contacts. This energizes the 1K relay coil through terminal "W1." 1. 1K5 contacts close. The circuit to the furnace blower motor is complete 2. 1K2 contacts close. The circuit to relay 2K is complete. 3. 1K4 contacts open. The circuit to V2 valve is not complete. 4. 1K1 open and closed contacts are reversed. This bypasses the storage sensor and places a resistor in the circuit. The collector sensor now controls the 3K relay. If the collector temperature is over 110°F the 3K relay is energized. If the collector temperature is under 110°F the relay is de-energized. B. Since 2K relay is energized, the 2K2 contacts are closed. The circuit to pump P3 is complete. C. Since the collector temperature is under 110°F, 3K relay is de-energized.

STEP SEQUENCE	EXPLANATION
Step 16 Depress Switch 9 ... Outdoor Temperature 20°F.	CONTROL SEQUENCE: NOTE: In this mode the 4K aquastat senses storage temperature above 90°F. 4K is switched. 4K1 open and closed contacts are reversed. The circuit to 2K relay coil is not complete. A. When the thermostat senses a demand for heat, it first closes the first stage contacts. This energizes the 1K relay coil through terminal "W1." 1. 1K5 contacts close. The circuit to the furnace blower motor is complete. 2. 1K2 contacts close. The circuit to relay 2K is complete. 3. 1K4 contacts open. The circuit to V2 valve is not complete. 4. 1K1 open and closed contacts are reversed. This bypasses the storage sensor and places a resistor in the circuit. The collector sensor now controls the 3K relay. If the collector temperature is over 110°F the 3K relay is energized. If the collector temperature is under 110°F the relay is de-energized. B. Since 2K relay is energized, the 2K2 contacts are closed. The circuit to pump P3 is complete. C. Since the collector temperature is under 100°F, 3K relay is de-energized. D. When the second stage bulb of the thermostat senses a demand for heat, the auxiliary heat relay is energized through terminal "W2."

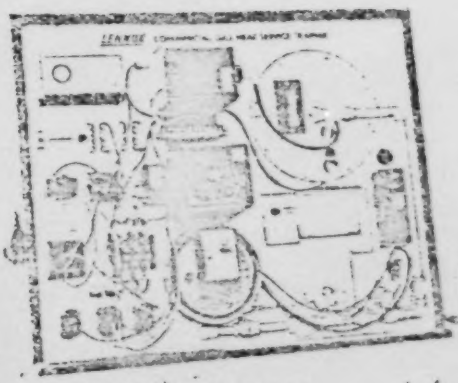
STEP SEQUENCE	EXPLANATION
Step 17 Depress Switch 5 ... Storage, 80°F or below	CONTROL SEQUENCE: A. When the thermostat senses a demand for heat, it first closes the first stage contacts. This energizes the 1K relay coil through terminal "W1." 1. 1K5 contacts close. The circuit to the furnace blower motor is complete. 2. 1K2 contacts close. The circuit to the gas valve is complete. 3. 1K4 contacts open. The circuit to valve V2 is not complete. 4. 1K1 open and closed contacts are reversed. This bypasses the storage sensor and places a resistor in the circuit. The collector sensor now controls the 3K relay. If the collector temperature is over 110°F the 3K relay is energized. If the collector temperature is under 110°F the relay is de-energized. B. Since the collector temperature is under 110°F, 3K relay is de-energized.
Step 18 Depress Switch 4 ... Sun	CONTROL SEQUENCE: A. The first stage contacts are already closed, energizing 1K relay through terminal "W1." 1. Contacts 1K2 and 1K5 are closed. 1K4 contacts are open. 2. 1K1 open and closed contacts are reversed. B. Since the collector temperature is over 110°F, the 3K relay is energized 1. 3K5 contacts are closed. The circuit to V2 valve is not complete. 2. 3K1 contacts are closed. The circuit is complete to pumps P1 and P2 3. 3K2 contacts are open. The circuit to the gas valve is not complete. C. The second stage of the thermostat heating contacts close. The circuit to the gas valve is complete.

STEP SEQUENCE	EXPLANATION
Step 19 Depress Switch 8 ... Outdoor Temperature 45°F	CONTROL SEQUENCE: A. When the thermostat senses a demand for heat, it first closes the first stage contacts. This energizes the 1K relay coil through terminal "W1." 1. 1K5 contacts close. The circuit is complete to the furnace blower motor. 2. 1K2 contacts close. The circuit to the gas valve is not complete. 3. 1K4 contacts open. The circuit to valve V2 is not complete. 4. 1K1 open and closed contacts are reversed. This bypasses the storage sensor and places a resistor in the circuit. The collector sensor now controls the 3K relay. If the collector temperature is over 110°F the 3K relay is energized. If the collector temperature is under 110°F the relay is de-energized. B. Since the collector temperature is over 110°F, 3K relay energizes. 1. 3K5 contacts close. The circuit to valve V2 is not complete. 2. 3K2 contacts open. The circuit to the gas valve is not complete. 3. 3K1 contacts close, completing a circuit to pumps P1 and P2.
Step 20 Depress Switch 12 ... Closed Solar Coil Limit	CONTROL SEQUENCE: Solar coil limit is open, de-energizing the circuit to V2. V2 valve routes fluid through solar coil.
Step 21 Depress Switch 11 ... Open Solar Coil Limit	CONTROL SEQUENCE: Solar coil limit is closed completing circuit to V2. V2 valve routes fluid to storage.
Step 22 Depress Switch 10 ... Outdoor Temperature 95°F	CONTROL SEQUENCE: A. Indoor blower relay is energized through the terminal "G" of the thermostat. Blower motor starts. B. The compressor is energized through the "Y1" terminal of the thermostat.

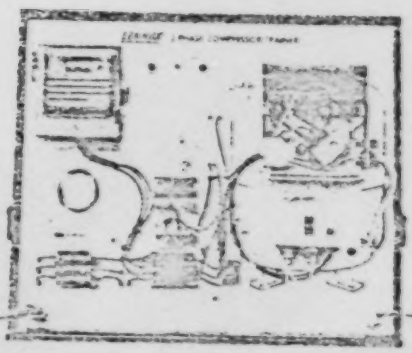


POWER SAVER TRAINER

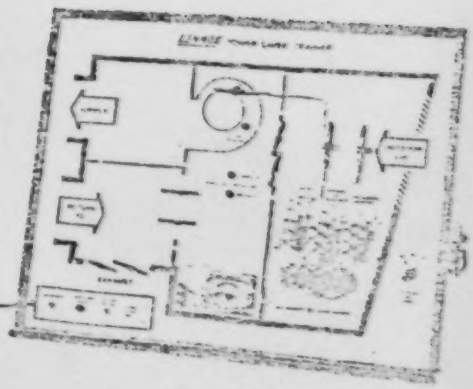
Pow'R SAV



Model ST-8



Model ST-5



Model ST-6

ST-5 three phase compressor trainer

ST-6 power saver trainer

ST-8 commercial gas heat service trainer

instructor manual

LENNOX JOB RELATED COURSES FOR HEATING • AIR CONDITIONING

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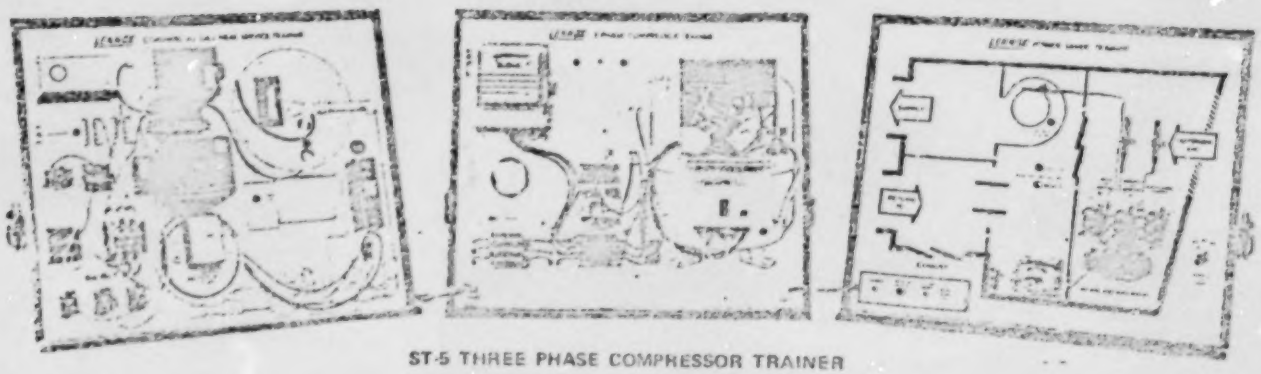
11

INTRODUCTION

This manual deals with the operation and service procedures used on commercial packaged rooftop heating – air conditioning and power saving equipment.

To adequately teach the operation and service of this commercial equipment, it is advisable to study it in individual sections. The logical breakdown is Heating – Air Conditioning and Power Saving.

Lennox has designed a series of trainers that will enable the instructor to teach each section of the commercial unit separately. The trainers are the ST-5 Three Phase Compressor Trainer, the ST-6 Power Saver Trainer, and the ST-8 Commercial Gas Heat Service Trainer.



ST-5 THREE PHASE COMPRESSOR TRAINER

ST-8 COMMERCIAL GAS HEAT SERVICE TRAINER

ST-6 POWER SAVER TRAINER

Each trainer has a series of switches used to program various faults into the trainer. When a fault has been programed into the trainer, the student then troubleshoots the circuit by observation and the use of test instruments to diagnose and locate the fault. These switches are number coded to a list of faults in this manual.

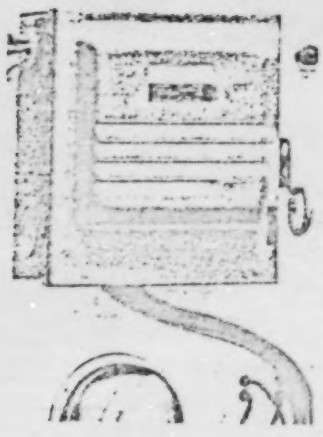
When the student thoroughly comprehends how each section functions, the trainers can then be electrically coupled together to simulate a complete commercial rooftop heating and air conditioning unit.

When shipped from the Lennox Educational Department, these trainers have been completely wired and tested. All commercial trainers use 120 volt power source.

For detailed information concerning commercial heating – cooling and power saving equipment, refer to the Phase III(S) Manual of the Lennox Job Related Training Course.

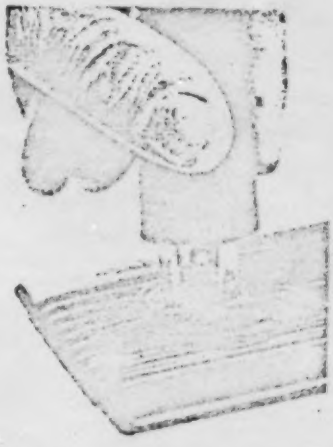
TEACHING SEQUENCE

1. Acquaint the student with all parts on the trainer and their function.
2. Lead the students through the schematic diagram, explaining how each electrical component is related to and inter-connected with others.
3. Run the trainer through a normal operative cycle in front of the class, discussing the sequencing and operation of the various components.
4. Discuss safety precautions which must be observed when operating the trainer. The student must learn to assume responsibility for his own safety which can only come through a complete understanding of the equipment. Prior to working with the equipment, the student must understand that the trainer can quickly be turned off in any one of three ways.
   a. Flip the disconnect switch on the front of the three phase trainer when trainers are connected together. When a trainer is used alone use disconnect switch on that trainer.
   b. Flip the power switch on the rear of the board to the "off" position.
   c. Pull the power cord from the classroom outlet.



MAIN DISCONNECT SWITCH

POWER SWITCH



POWER CORD

CAUTION: *When the Power Switch on the back of the trainer is in the "on" position, there is power supplied to the disconnect switch located on the front of the board. When the disconnect switch is in the "on" position, there is 208V three phase power to the exposed wiring on the board. Also there could be 10,000V output from the spark generator.*

5. The student is now ready to approach the trainer. From the fault index, select and switch in any one of the faults listed.
6. Inform the student of the customer complaint related to the selected fault. This should be the only information the student needs.
7. The student troubleshoots by observation and the use of test instruments to diagnose and locate the fault. The student should be judged on the accuracy of his diagnosis and the length of time he takes to arrive at it.

NOTE: No component or control on the trainer should be removed or replaced by the student. He should indicate to the instructor what corrective measures he would take.

POWER SAVER™ TRAINER

TRAINER DESCRIPTION AND USE

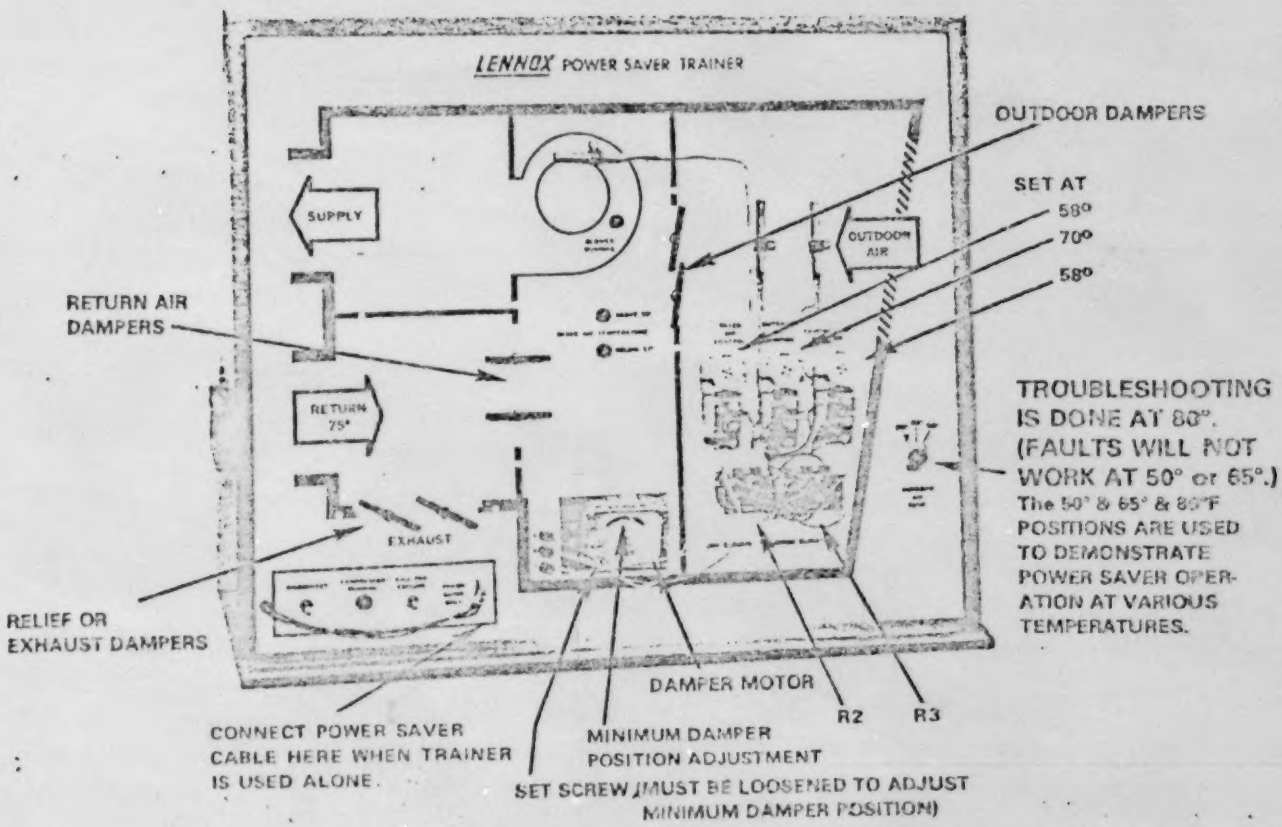
The Power Saver Trainer simulates the operation of mixed air temperature control systems used on rooftop heating and air conditioning equipment. The ST-6 Power Saver Trainer is used to:

(a) Demonstrate the sequence of operation of a Power Saver

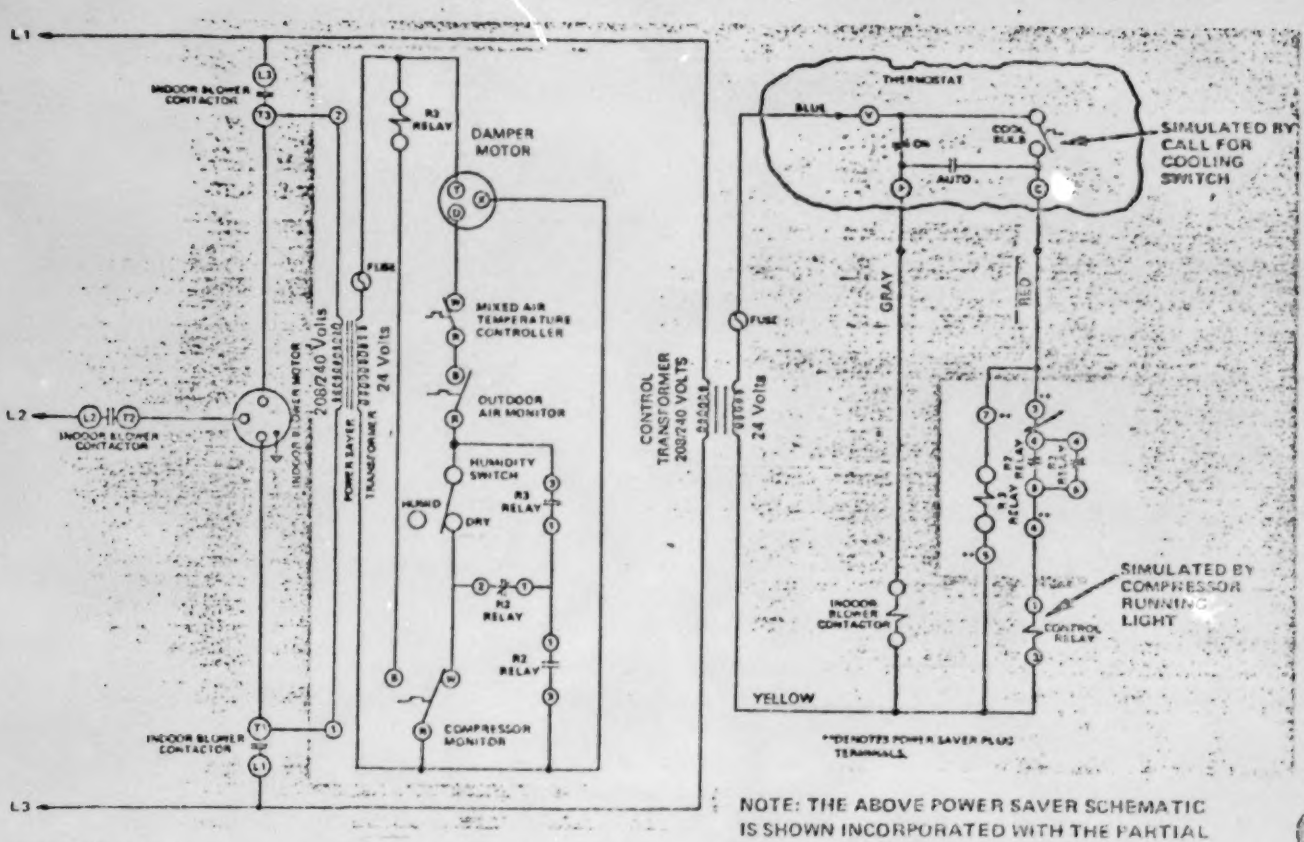
(b) Test the student's understanding of Power Saver operation

(c) Check the student's ability to troubleshoot power saving equipment and solve faults which have been programed into the trainer

Model ST-6


LENNOX POWER SAVER TRAINER
SUPPLY
OUTDOOR AIR
RETURN 75°
EXHAUST
OUTDOOR DAMPERS
SET AT
58°
70°
58°
RETURN AIR DAMPERS
TROUBLESHOOTING IS DONE AT 80°. (FAULTS WILL NOT WORK AT 50° or 65°.)
The 50° & 65° & 80°F POSITIONS ARE USED TO DEMONSTRATE POWER SAVER OPERATION AT VARIOUS TEMPERATURES.
RELIEF OR EXHAUST DAMPERS
DAMPER MOTOR
R2
R3
CONNECT POWER SAVER CABLE HERE WHEN TRAINER IS USED ALONE.
MINIMUM DAMPER POSITION ADJUSTMENT
SET SCREW (MUST BE LOOSENED TO ADJUST MINIMUM DAMPER POSITION)

ST-6 POWER SAVER SCHEMATIC WIRING DIAGRAM



208 240V/60 Hz/ 3 ph

SHADED AREAS = COOLING UNIT WIRING
UNSHADED AREAS = POWER SAVER WIRING

NOTE: THE ABOVE POWER SAVER SCHEMATIC IS SHOWN INCORPORATED WITH THE PARTIAL WIRING OF A TYPICAL COOLING UNIT, SINCE THE POWER SAVER HAS NO POWER SOURCE OF ITS OWN.

POWER SAVER OPERATION

The purpose of mixed air temperature control systems is to use outdoor air for cooling whenever it has cooling capacity. Mixed air temperature control systems are found on many kinds of rooftop units to maximize their efficiency.

Lennox terms its mixed air temperature control system the Power Saver. Power Saver equipment contains three sets of motor-driven dampers: outdoor dampers, return air dampers, and relief or exhaust dampers.

Outdoor dampers bring in controlled amounts of outdoor air. This "free" outdoor air is used to augment or replace mechanical cooling whenever the air has cooling capacity. Utilization of this outdoor air is the energy and cost saving feature of the Power Saver.

The outdoor dampers always assume one of the following positions in order to meet the various indoor/outdoor climatic conditions.

Minimum open position: Dampers are partially open to admit a constant supply of outdoor air whenever the system is energized. This minimum position provides "fresh" air to the system and is adjustable in the field.

Maximum open position: Dampers are fully open to provide maximum amount of "free" outdoor air cooling.

Closed position: Dampers are fully closed to prevent outdoor air from entering whenever the system is de-energized.

Power Saver Operation (continued)

Return air dampers control the amount of return air that is re-circulated through the system. Relief or exhaust dampers expel controlled amounts of return air to the outdoors.

The return air dampers are mechanically linked to the outdoor dampers. The relief dampers are mechanically linked to the return dampers. The return air dampers work in opposition to the outdoor dampers, the relief dampers work in opposition to the return air dampers. For example, when the outdoor dampers are opening to the maximum position to admit cool air, the return air dampers are closing to prevent the warmer return air from being re-circulated through the system. At this same time, the relief dampers are opening to expel this warm return air to the outdoors.

Three adjustable, temperature sensitive instruments dictate Power Saver operation:

The compressor monitor senses outdoor air temperature and is usually set at 58°F. This control locks out compressor operation when the outdoor temperature is below the 58°F set point.

The outdoor air monitor also senses outdoor air temperature and is usually set at 70°F. This control prevents the outdoor dampers from opening to maximum position when the outdoor temperature is above the 70°F set point.

The mixed air temperature controller senses mixed air temperature (mixture of indoor return air and outdoor air) and is usually set at 58°F. This control reacts to mixed air temperature changes by modulating the Power Saver dampers.

SEQUENCE OF OPERATION FOR POWER SAVER TRAINER

1. Insert connecting plug in receptacle on trainer front.
2. Set Power Saver controls at their usual settings (compressor monitor at 58°F, outdoor air monitor at 70°F, mixed air temperature controller at 58°F).
3. Flip power switch at back of trainer and disconnect switch on front of trainer to "on." The trainer will now respond as if it were circuited into a cooling unit. (The blower is running.)

NOTE: The manually operated, two-position Climate Switch affects Power Saver operation only when outdoor temperature is between 58°F and 70°F. When outdoor temperature does not fall within this temperature range, the Climate Switch may be set at either position without affecting Power Saver operation.

Sequence With Outdoor Temperature Below 58°F

1. Set outdoor air temperature switch at 50°F.
2. Since the Power Saver has continuous blower operation, the indoor blower contactor has energized the indoor blower.
   This is indicated by a lighted bulb on the trainer.
3. Power is supplied to terminals T and X of the damper motor whenever the blower is energized. The damper motor drives the outdoor dampers to the minimum open position.

4. Since the outdoor temperature of 50°F is below the 58°F setting of the compressor monitor, the monitor contacts are in the R and B position. When in this position, terminal D of the damper motor cannot be energized through the compressor monitor circuit, and the outdoor dampers are prevented from opening to maximum position.

5. With compressor monitor contacts in the R and B position, R2 relay is energized. The energized R2 relay affects two sets of contacts in the control voltage and Power Saver circuits.

6. The temperature inside the building served by the Power Saver rises when "heat producers" in the building (motors, lights, people, etc.) are active. When this condition occurs the thermostat will call for cooling. Flip the call for cooling switch "on" to simulate this condition on the trainer.

7. R3 relay is energized on the call for cooling, affecting two sets of contacts in the control and Power Saver circuits. The opened R2 and R3 contacts in the control circuit prevent the control relay from being energized, and the compressor is kept off the line. The energized R2 and R3 relays close contacts in the Power Saver circuit to the damper motor.

8. Since the outdoor temperature of 50°F is below the outdoor air monitor setting of 70°F, monitor contacts (R and B) are closed.

9. As the mixed air temperature rises above 59°F (because of "heat producers" inside the building), a bulb lights on the trainer. A mixed air temperature above the mixed air temperature controller setting of 58°F causes contacts R and W to close. Power now travels through closed R2 and R3 relay contacts, the outdoor air monitor, and the mixed air temperature controller, and energizes terminal D of the damper motor. With power supplied to terminals T, X and D, the outdoor dampers open toward maximum position.

   The increased amount of incoming cool air causes the mixed air temperature to drop below 58°F. A lighted bulb on the trainer notes the temperature drop. When this condition occurs, mixed temperature controller contacts R and W open, de-energizing terminal D. The outdoor dampers now close toward minimum position.

   The outdoor dampers continue to modulate, opening toward maximum position and closing toward minimum position as the mixed air temperature controller works to maintain a 58°F mixed air temperature.

10. Flip call for cooling switch "off."

Sequence With Outdoor Temperature Between 58°F and 70°F

1. Set outdoor air temperature switch at 65°F.

2. Since the Power Saver has continuous blower operation, the indoor blower contactor energizes the indoor blower (indicated by lighted bulb on trainer).

"Dry Climate"

3. Set Climate Switch to "Dry Climate."

4. Since the outdoor temperature of 65°F is above the compressor monitor setting of 58°F, monitor contacts are in the R and W position and R2 relay is de-energized.

5. Since the outdoor temperature of 65°F is below the outdoor air monitor setting of 70°F, monitor contacts (R and B) are closed.

6. As the mixed air temperature rises above the mixed air temperature controller setting of 58°F (because of "heat producers" inside the building), mixed air temperature controller contacts R and W are closed. Power is now supplied to terminal D through compressor monitor contacts R and W, the "Dry Climate" switch, the outdoor air monitor, and the mixed air temperature controller. With terminal D now energized, the damper motor drives the outdoor dampers to maximum open position. This provides maximum "free cooling" benefits from the outdoor air. The outdoor dampers are at maximum position regardless of whether there is a call for cooling or not.

7. If outdoor air alone cannot sufficiently cool the building, the thermostat will call for cooling. Flip the call for cooling switch "on" to simulate this condition on the trainer.

8. On the call for cooling, the control relay is energized through the closed contacts of R2 relay and the compressor is brought on the line. A lighted bulb on the trainer indicates when the compressor is operating. The R3 relay is also energized.

9. Flip call for cooling switch "off."

"Humid Climate"

10. Set Climate Switch to "Humid Climate."

11. The outdoor dampers return to minimum position because the circuit to terminal D has been opened by flipping the switch to "Humid Climate." The outdoor dampers close to minimum position to prevent humid outdoor air from entering the system.

12. Since the Power Saver is at "Humid Climate" and is not receiving maximum "free cooling" benefits from the outdoor air, the mixed air temperature rises more quickly because of inside "heat producers." When mixed air temperature rises above the 58°F set point, mixed temperature controller contacts R and W close.

13. If the outdoor air cannot sufficiently cool the building, the thermostat will call for cooling. Flip the call for cooling switch "on" to simulate this condition on the trainer.

14. The control relay and R3 relay are energized on the call for cooling. The control relay energizes the compressor (indicated by lighted bulb on trainer.).

    The energized R3 relay closes a set of N.O. contacts in the Power Saver circuit. Power now travels through the compressor monitor, bypasses the "Humid Climate" switch by going through R2 and R3 contacts, and energizes terminal D of the damper motor. The outdoor dampers open to maximum position to permit maximum "free cooling," and the dehumidifying effect of mechanical cooling keeps the humidity level in check.

15. Flip call for cooling switch "off."

Sequence With Outdoor Temperature Above 70°F

1. Set outdoor temperature switch at 80°F.

2. Since the Power Saver has continuous blower operation, the indoor blower contactor energizes the blower (indicated by lighted bulb on trainer).

3. Since the outdoor temperature of 80°F is above the outdoor air monitor setting of 70°F, monitor contacts (R and B) are open. These open contacts prevent power to terminal D and the outdoor dampers are at minimum position to reduce the amount of incoming warm air.

4. At this temperature the outdoor air does not have the capacity to cool the building and the thermostat will call for cooling. Flip the call for cooling switch "on" to simulate this condition on the trainer.

5. The control relay is energized and brings on the compressor (indicated by lighted bulb on trainer) when the thermostat calls for cooling. The outdoor dampers remain at minimum position to admit outdoor fresh air.

POWER SAVER TRAINER CHECKOUT PROCEDURE AT 80°F

Troubleshooting on the Power Saver Trainer can only be done when the outdoor air temperature switch is set at 80°F. The trainer will emit improper fault symptoms when the outdoor air temperature switch is set at 50°F or 65°F. Proper Power Saver checkout procedure when outdoor temperature is 80°F is as follows:

1. Preset conditions:
   a. Outdoor air temperature switch set at 80°F.
   b. Compressor monitor set at 58°F.
   c. Outdoor air monitor set at 70°F.
   d. Mixed air temperature controller set at 58°F.
   e. Climate switch set at "Dry."

2. Flip main disconnect switch "on."
   a. Outdoor dampers open to minimum position.
   b. Blower bulb is lighted.
   c. Mixed air temperature above 59°F bulb is lighted.

3. Flip call for cooling switch "on."
   a. Compressor bulb is lighted.
   b. Outdoor dampers at minimum open position.
   c. R3 relay makes "click" sound as it is energized.

4. Rotate compressor monitor to a setting above the outdoor air temperature of 80°F.
   a. Compressor light goes off.
   b. R2 relay "clicks" as it is energized.

5. Return compressor monitor setting to 58°F.
   a. Compressor bulb re-lights.
   b. R2 relay "clicks" as it is de-energized.

6. Rotate outdoor air monitor to a setting above the outdoor air temperature of 80°F.
   The outdoor dampers open to maximum position.

7. Rotate mixed air temperature controller to a setting above the outdoor air temperature of 80°F.
   The outdoor dampers return to minimum open position.

8. Return mixed air temperature controller setting to 58°F.
   The outdoor dampers open to maximum position.

9. Return outdoor air monitor setting to 70°F.
   The outdoor dampers return to minimum open position.

ST-6 POWER SAVER TRAINER

Fault Index

S1 – Loss of Charge on Mixed Air Temperature Controller Bulb
S2 – Open Wire Between Terminal 3 of the Power Saver Plug and Terminal 4 of Relay 2
S3 – Open Secondary Winding of Power Saver Transformer
S4 – Low Voltage to Power Saver
S5 – Reversed Leads of Power Saver Plug
S6 – Open R & B Contacts of Outdoor Air Monitor
S7 – Welded R & B Contacts of Outdoor Air Monitor
S8 – Loss of Charge on Compressor Monitor Bulb

Fault Instructions

No component or control on the trainer should be removed or replaced by the student. Remember, all troubleshooting must be done with the outdoor air temperature switch in the 80°F position.

Use the POWER SAVER TRAINER CHECKOUT (pages 14 and 15) as a guide for isolating the faults.

Fault Description

S1 – Loss of Charge on Mixed Air Temperature Controller Bulb

Customer Complaint – Excessive Power Consumption During Periods When Power Saver Should be Operating

Symptoms – The outdoor air dampers will not open beyond the minimum position.

S2 – Open Wire Between Terminal 3 of the Power Saver Plug and Terminal 4 of Relay 2

Customer Complaint – No Cooling

Symptoms – The compressor will not operate on a call for cooling.

S3 – Open Secondary Winding of Power Saver Transformer

Customer Complaint – Excessive Power Consumption During Periods When Power Saver Should be Operating

Symptoms – The dampers will not open from closed position.

S4 – Low Voltage to Power Saver

Customer Complaint – Excessive Power Consumption During Periods When Power Saver Should be Operating

Symptoms – Dampers not operating properly. The Power Saver motor may not operate, or will operate but the clutch makes slipping noises.

Instructor Note:
When this fault is programed into the trainer, normal voltage fluctuation to the trainer may cause the damper motor to react in two different ways.

(1) The motor will not move at all.

(2) The motor will try to operate, but the clutch will make a loud slipping noise.

S5 – Reversed Leads of Power Saver Plug

Customer Complaint – None, as the problem should be caught during installation.

Symptoms – The compressor will not run and the Power Saver dampers will not operate properly in the humid position.

S6 – Open R & B contacts of Outdoor Air Monitor

Customer Complaint – Excessive Power Consumption During Periods When Power Saver Should be Operating

Symptoms – The outdoor air dampers will not open beyond the minimum position.

S7 – Welded R & B Contacts of Outdoor Air Monitor

Customer Complaint – Excessive Power Consumption During Periods When Power Saver Should be Operating

Symptoms – The outdoor air dampers will not return to minimum position.

S8 – Loss of Charge on Compressor Monitor Bulb

Customer Complaint – No Cooling

Symptoms – The compressor will not operate on a call for cooling.

HEAT PIPE

THE HEAT PIPE

A

TABLE OF CONTENTS

1. General Characteristics of the Heat Pipe
2. Simplified Theoretical Analysis
3. Introduction to the Heat Pipe Mini-Lab ©
4. Suggested Experiments with the Mini-Lab ©

HEAT PIPE CORPORATION OF AMERICA,

1. GENERAL CHARACTERISTICS OF THE HEAT PIPE

The Heat Pipe is a relatively simple and inexpensive device for transporting heat energy from a heat producing source to a location site where that energy may either be dissipated or utilized. When used within its capacity the Heat Pipe can transport thermal energy at a rate as much as 500 times that of an equivalent mass of copper (bar or rod). Since no moving parts are involved in its operation, the Heat Pipe can function quietly and reliably for many years without service or adjustment.

The principle of the Heat Pipe is not complicated. When water or other liquid is heated it absorbs and retains thermal energy. If this latent energy is then caused to travel within a confined vessel to a point where it can be cooled, the vapor (steam in the case of water) will condense and give up its latent heat of vaporization.

It can be seen that if this process were not self sustaining the total amount of liquid in the heated section would rapidly vaporize and the heat exchange would not occur. Moreover, if trapped non-compressible gases such as air were permitted to impede the flow of the vapor, heat transfer could not occur. If water were chosen as a working fluid (because of its high latent heat of vaporization) the device would not begin to function until heat input had reached the boiling point of water under normal atmospheric pressure.

The foregoing conditions are typical of a normal home steam heating system where:

1. The working fluid must be returned to the boiler or evaporator.
2. There must be no non-condensable gases to impede the flow of steam.
3. The working temperature of the boiler or evaporator must be greater than 212°F.

Here the working fluid is returned to the boiler in the basement by gravitational flow through the steam pipes. Steam generated in the boiler forces the non-condensable gases out of the system through valves attached to the radiators throughout the home. Conventional home boilers operate at or near 212°F and steam-heat home heating systems are efficient means of transporting heat from the basement to the other liveable portions of one's home.

The Heat Pipe operates on the same principle as the normal home steam heating system except that *it has no valves or return pipes and, in most cases, is required to operate below 212°F.* How then are the three parameters typical of the home steam heating system accomplished by the Heat Pipe?

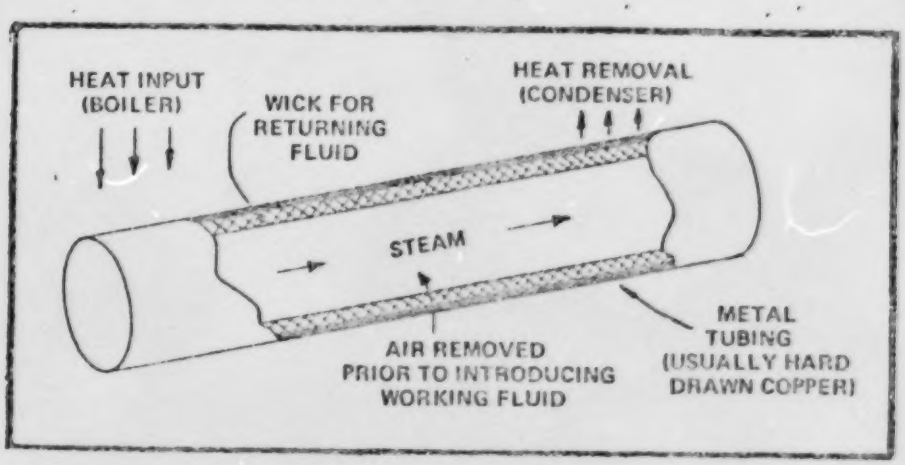
1. When the vapor (or steam) condenses on the cooler walls of the Heat Pipe in the dissipator section it must be

returned to the heat input (boiler) section in order to make the Heat Pipe self sustaining. This is accomplished by means of a wick which functions in a manner similar to an ink blotter - transporting fluid against gravity by capillary action. In addition to the capillarity of the wick a small pressure differential is developed between the boiler end and the condensing end of the pipe forcing the return of fluid to the boiler section.

2. In order to remove the non-condensable gases which impede or restrict the flow of vapor, the manufacturer of the Heat Pipe reduces the internal pressure of the pipe to a maximum of 300 microns prior to charging with the working fluid. This insures that the remaining non-condensable gases present in the vessel are of no significant consequence in the normal operation of the pipe.

3. The working temperature of the Heat Pipe is determined by the nature of the working fluid with which it is charged. When the internal pressure of the vessel is lowered (as in No. 2 above) to below 300 microns when charged the working fluid will volatilize far below its boiling point at atmospheric pressure. When water is used as the working flyid, for example, it will boil rapidly at or near 32°F.

Thus we have all of the physical requirements of transporting heat similar to those found in steam heating systems contained in a small diameter sealed tube.



A very simple Heat Pipe may be constructed of a small diameter metal, ceramic, or glass tube cut to the length desired. A wick is fabricated from a material which can transport a fluid against gravity by capillary action. Fine mesh screen or compacted fibers may be

used for this purpose. The wick is installed so that it is in intimate contact with the internal wall of the vessel throughout its entire length. The non-condensable gases are then evacuated from the pipe and the working fluid, e.g. water, is introduced. The pipe is then sealed so as to insure against losing the integrity of the vacuum.

The wick, of course, must be of the proper design and constructed of a material which will accomodate the quantity of condensate which must be continuously transported. In addition, the volume of working fluid must be calculated with relation to the volume and geometry of the pipe in order to sustain the heat flow characteristics without causing problems such as "delayed reaction" and the phenomena known as "burn-out", both of which will be explained in section 3, to follow.

2. SIMPLIFIED THEORETICAL ANALYSIS

In the design of a Heat Pipe for a given application there are certain parameters some of which can be changed and others which are constant. These constitute the physics of Heat Pipe design for a given application.

It is not the intent of this simplified analysis to assist engineers in the design of Heat Pipes, rather that we establish which of the aforementioned parameters are fixed due to the particular and specific application, and those which can be varied in order to effect a more desirable and efficient transfer of thermal energy. In all cases the degree of effect on heat transfer capacities of each parameter will be explained in uncomplicated terms in order to illustrate the percentage of overall increase or decrease in performance which can possibly be achieved.

1. The maximum theoretical heat transfer can be calculated from Cotters Theory as shown in equation (1).

Equation (1)

$$Q = \left\langle \frac{p\ o\ h}{u} \right\rangle \left\langle \frac{k\ A}{L'} \right\rangle \left\langle \frac{p\ g}{gc\ o} \right\rangle \left\langle lm - L\ \cos \phi \right\rangle$$

Where -

h	=	latent heat of vaporization of the working fluid at the operating temperature, i.e. temperature of the adiabatic section of the Heat Pipe.
o	=	surface tension of the fluid-wick-heat pipe wall interface.
p	=	liquid density.
u	=	dynamic viscosity of liquid at operating temperature.
k	=	permeability of the wick (measure of porosity).
A	=	cross sectional area of liquid flow path.
L'	=	distance from center of evaporation section to center of condenser section.
g	=	acceleration of gravity.
gc	=	dimensional constant.
lm	=	wicking height due to capillary actions in wick.
L	=	overall length of heat pipe.
ϕ	=	angle of inclination of Heat Pipe from vertical.

2. Equation (1) may be rewritten in the following manner for a Heat Pipe operating in a horizontal attitude and under essentially isothermal conditions, as shown in equation (2).

$$Q_{max.} = \left\langle \frac{h\ \rho\ g}{u\ g_c} \right\rangle \left\langle k\ l_m \right\rangle \left\langle \frac{A}{L'} \right\rangle$$

Equation (2)

$$= \left\langle B(T) \right\rangle \left\langle W \right\rangle \left\langle G \right\rangle$$

Where -

B(T) is a bulk parameter which is solely a function of temperature for a given fluid. The selection of the working fluid will influence this parameter significantly. The working fluid must, however, be chemically compatible with the material of which the Heat Pipe is made and be in the range of liquid-vapor equilibrium at operating temperatures.

W - is a wick parameter which approximates 9.0×10^{12} for a conventional wire screen wick (See Table 1). For wick materials other than wire screen or for multi-artery wick structures this parameter can vary over several orders of magnitude and for high performance Heat Pipe design becomes one of the most significant parameters.

G - is a geometric parameter which is a function of Heat Pipe dimensions. For a given Heat Pipe configuration, this parameter is fixed, however the choice of geometric design can greatly affect the performance.

3. If one considers water as the working fluid at an operating temperature of 212°F., it is seen as equation (3).

Equation (3)

$$Q_{max.} \simeq 4.8 \frac{A}{L'}$$

Where -

A - is the cross sectional area through which liquid flows.

L' - is the effective length of the pipe.

4. Equation (3) can be used to determine the approximate maximum theoretical heat transport capability of a wire-screen-wick Heat Pipe operating at 212°F. with water as the working fluid. Experimental results show this to be a conservative

analysis since maximum heat transfer rates several times greater than the theoretical predicted rates are not uncommon. In point of fact, the multi-artery wick [1] of the Heat Pipe Corporation of America, has been operated in steady-state with heat fluxes greater than theoretically predicted by an order of magnitude or greater.

[1] Wick design patent pending.

TABLE 1. WICK - FLUID CHARACTERISTICS

Wick Type [2]	% Porosity	Mean Pore Diameter (Microns)	K Permeability $ft^2 \times 10^{10}$	lm Wicking Hgt. (inches)
200 m Ni Powder	65.8	>70	0.294	9.7
500 m Ni Powder	54.0	~80	0.087	>16.0
50 mesh Ni Screen	62.5	-	0.715	1.9
100 mesh Ni Screen	67.9	>100	0.164	4.4
200 mesh Ni Screen	67.6	~50	0.0834	9.2
0.0004 in. Ni Fibers	68.9	26.5	0.0163	>16.1
0.0013 in. SS Fibers	80.8	>70	0.210	9.0
0.0030 in. SS Fibers	82.8	>80	1.250	5.3

[2] H. R. Kunz, et. al., NASA CR-812, June 1967

Summary

The theoretical analysis shows that the performance of a Heat Pipe is a function of four separate variable groups:

(1) The fluid bulk properties, B(T)

(2) The fluid viscosity and capillary properties, (Klm)

(3) The geometric properties, $(\frac{A}{L'})$

(4) The angle of inclination from vertical, (Ø)

Variation of any one or more of these groups will affect the operation of the Heat Pipe. Any experimental work must be carefully controlled so that only one variable is changed at any one time.

3. INTRODUCTION TO THE HEAT PIPE MINI-LAB

Heat Pipes in the Mini-Lab kit are made of various diameter copper tubing. The kit contains several pipes of different lengths and diameters capable of transporting up to 300 watts of heat from a source one or two feet from its dissipators.

As one progresses into the experiment portion of this text he will appreciate more fully that the temperature gradients in a working system are not primarily in the Heat Pipe but are, in fact, losses due to the natural convection losses in the metal attachments to the Heat Pipes, i.e. bolt-on heaters and bolt-on fins, and to the interfaces between these attachments and the pipes. A great deal of care has been taken to minimize these gradients in preparing this kit, however, they still exist and will account for a small discrepancy in the readings obtained. This discrepancy should not exceed five percent. If it does, one should examine his temperature measuring gauges and probes for accuracy.

Note - In the unlikely event that one finds large inconsistencies in the reading of a particular Heat Pipe, he should perform the following experiment on that pipe -

Insert one end of the pipe (3 to 5 inches) into a container of water at a temperature of 140° to 160°F. The fluid in the pipe should boil immediately. This can be detected as a vibration felt by the fingertips at the opposite end of the pipe. In less than 1.5 minutes the temperature at the opposite end of the pipe should be at least 120°F. when measured at a distance of 3 inches from that end.

If the pipe fails to respond as detailed in the above test it should be returned to Heat Pipe Corporation of America, for replacement free of charge.

EXPLANATION OF ILLUSTRATIONS

Figure I _____ shows the method of attaching the dissipating fins and the heater assembly to any of the Heat Pipes included in the kit. Note that there are separate grooves milled into each of these parts. These accept only the proper diameter pipe and are intended to minimize the heat loss between the outer wall of the Heat Pipe and the fins or the heater. A liberal coating of silicone grease will also help to reduce heat loss.

Figure II _____ shows the method of adapting the Heat Pipe assemblies to the rotatable display stand. Heat Pipes, once mounted in this stand, can easily be oriented in any attitude from vertical to horizontal thus permitting the heat source to be either above or below the dissipating fins, or in the same horizontal plane with them.

The Heat Pipe Mini-Lab also contains copper bars of similar geometry in order that one may perform comparison tests with the Heat Pipes. The copper bars are mounted to the stand, and the dissipating fins and heater assemblies attached in precisely the same manner as explained above for the Heat Pipes.

Figure III _____ applies only to those kits which contain a blower and blower adaptor. Note that the blower, once mounted to the adaptor, can be coupled to the dissipating fins without the use of fastening devices.

Figure IV _____ shows the proper method for clamping the heater and the heat pipe into the block to form the heater assembly. Note both heater and heat pipe should fully engage entire length of grooves.

4. SUGGESTED EXPERIMENTS WITH THE MINI-LAB ®

1. Effect of Attitude on Heat Pipe Performance

When a Heat Pipe is located in a gravitational field, the pumping capacity of the wick is affected by gravity. This effect can be demonstrated by operating the pipe with its evaporator section (heat input end) below the condenser section (finned end), recording the heat transfer characteristics in this attitude, and then changing the attitude of the Heat Pipe so that the condenser section is below the level of the evaporator section. A comparison of the heat transfer characteristics between these two attitudes of operation when run at various angles from the horizontal will demonstrate the following:

(1) When the evaporator section is below the condenser section, gravity aids the wick in returning the condensate to the evaporator and the Heat Pipe can transport a greater amount of heat.

(2) When the reverse is true, gravity retards the return of the condensate and a reduction in heat transport is experienced.

(3) The amount of heat which can be transported in a given Heat Pipe is dependent upon the degree of difference in elevation, but has its own curve peculiar to the design of the Heat Pipe.

Experiment A (Heat Pipe Attitude)

1. Level the stand by adjusting the three leveling screws in the base of the stand until bubble is in the center of the circle on the level.
2. Attach heater assembly and dissipating fins to a 1/2" diameter by 20" length Heat Pipe (Fig. I, Sect. 3)
3. Attach thermocouple to heater assembly and one to the Heat Pipe 3" from the dissipating fins and insulate the pipe and heater (Fig. III, Sect. 3)
4. Clamp this assembly into the stand (Fig. II, Sect. 3). Adjust the attitude of the pipe so that evaporator section is 3° below condenser section as indicated on the stand's dial.

   Note: If your kit contains a blower assembly it may be attached as in Fig. IV, Sect. 3. In this case all increases in heater wattage required in this experiment can be in 25 watt increments instead of 10 watt.
5. Activate the heater to provide 10 watts of power input (25 watts if blower is used).
6. Record on a graph (plotting temperature versus input watts) the temperature at both thermocouples after equilibrium has been reached.

7. Increase the input power in increments of 10 watts (25 blower used) and record the temperature of both thermocouples, again after equilibrium is reached. It should be noted that temperatures plotted on the graph as recorded from both thermocouples should be a linear function of the input wattage.

8. Continue as in paragraph 7 above until a marked change occurs in the linear temperature rise with increased power input. This marked change will be recognized by an abnormal increase in the temperature of the evaporator corresponding to a notable increase in temperature of the pipe close to the dissipators. This condition is called "burn-out" and is the limit of the heat transporting capabilities of the Heat Pipe.

9. Record the input wattage and temperature of both thermocouples at this point. Do not allow the Heat Pipe to continue to operate under these conditions for longer than 5 minutes or the pipe and/or heater may be damaged due to excessive heat.

10. Deactivate the heater and allow pipe to cool to near room temperature. Readjust the angle of the Heat Pipe so that the condenser section is now 3° below the evaporator section.

11. Reactivate the heater and repeat steps 5, 6, 7, 8, and 9, recording all temperatures as before.

12. Repeat steps 5, 6, 7, 8, and 9 for Heat Pipe attitudes where the evaporator is 6°, 9°, 12°, and 15° below the condenser and 6°, 9°, 12°, and 15° above the condenser. Be certain to record all temperatures, paying particular attention to the point at which burn-out occurs.

QUESTIONS

1. Does burn-out occur with less input power when the evaporator is above or below the condenser?
2. Are the heater temperatures for a given input wattage higher or lower when the evaporator is above the condenser?
3. Are the heater temperatures higher or lower when the evaporator is 3° below the condenser as compared to when it is 15° below the condenser?
4. Are the heater temperatures higher or lower when the evaporator is 3° above the condenser as compared to when it is 15° above the condenser?
5. Are the recorded temperatures of the heater and the Heat Pipe a linear function of input power to the Heat Pipe at all angles both positive (condenser above evaporator) and negative (condenser below evaporator)?
6. What is the burn-out point of a 1/2" diameter 20" length Heat Pipe of the design supplied in this kit at 3° positive attitude with the 180° sq. in. surface area dissipators supplied and with no cooling air?

2. Effect of Heat Pipe Length on Performance

As the Heat Pipe length is increased the power which can be transported by otherwise similar Heat Pipes is reduced. This is because of increase in the viscous drag caused by turbulent and frictional losses in the vapor path due also to increased length. These effects result in higher heater temperatures for a given input wattage and a lower burn-out point

Experiment B (Heat Pipe Length)

1. Set up the Heat Pipe Mini-Lab according to steps 1, 2, 3, and 4 of Experiment A.

2. Perform steps 5, 6, 7, 8, and 9 of Experiment A. Be sure to record all data.

3. Adjust blower assembly so that it is at least 6" closer to the evaporator assembly. The thermocouple on the outside of the Heat Pipe must now be necessarily 1 1/4" from the dissipators instead of 3", however, this change in location will have very little effect on recording the pipe's performance accurately.

4. Repeat steps 5, 6, 7, 8, and 9 of Experiment A, using the shorter length, similar diameter, Heat Pipe. Record all required temperatures and input wattages.

5. Compare the results of these two experiments, especially note temperatures versus input wattages, and the point at which the Heat Pipe reaches the burn-out condition.

QUESTIONS

1. Can a Heat Pipe of greater length transport more or less heat than one of lesser length?
2. What causes Heat Pipes of different lengths to have greater or lesser heat transporting capabilities?
3. Analyzing the data recorded, what effects would a Heat Pipe of even greater length than 20" have on heater temperature and burn-out if operated at the same wattage?
4. Which is the more significant in Heat Pipe performance - greater length or attitude of the pipe?

3. Effect of Diameter on Heat Pipe Performance

As a Heat Pipe is reduced in diameter, so also is its capacity to transport heat reduced. Three factors act to reduce the heat transfer capacity of any Heat Pipe:

(1) When the effective area available for liquid flow is reduced, frictional losses in the wick are increased.

(2) When the flow passage for vapor is reduced, vapor flow losses through friction and turbulence are increased.

(3) Entrainment losses at the liquid-vapor interface increase as the liquid and vapor velocities at a given heat flux are increased.

These combined effects can be demonstrated on the Heat Pipe Mini-Lab in the following manner:

Experiment C (Effects of Diameter)

1. Set up the Heat Pipe Mini-Lab according to steps 1,2,3 and 4 of Experiment A.
2. Perform steps 5,6,7,8, and 9 of Experiment A. Be sure to record all data.
3. Replace the 20" length by 1/2" diameter Heat Pipe with a 20" length by 3/8" diameter Heat Pipe.
4. Connect all thermocouples as in previous experiments with the 1/2" diameter pipe.
5. Repeat steps 5,6,7,8, and 9 of Experiment A with the smaller diameter Heat Pipe. Record all required temperatures and input wattages.
6. Compare the results of these two experiments, especially the temperatures versus input wattages. Note the burn-out point.

QUESTIONS

1. Can a Heat Pipe of larger diameter transport more or less thermal energy than one of lesser diameter but of the same length?
2. What causes Heat Pipes of greater diameters to have greater or lesser heat transfer capacities?
3. Analyzing the data recorded, what effects, if any, would a Heat Pipe 1/4" in diameter and of the same length have on heat transfer capacity?
4. Is greater length or larger diameter the more significant in Heat Pipe performance?

4. Effect of Working Fluid on Heat Pipe Performance

Heat Pipe performance is significantly affected by the selection of the working fluid. Various working fluids may be characterized by a parameter known as the "figure of merit". For Heat Pipes operating in a temperature range of 10°C. to 200°C., water is by far the best working fluid available.

The effect of the working fluid on Heat Pipe performance can best be demonstrated by comparing a water charged pipe with a

methanol charged pipe of the same length and diameter. The methanol charged Heat Pipe, however, has the capacity to operate below 0°C., and thus has distinct advantages for many applications.

Experiment D (Effect of Working Fluid)

1. Set up the Heat Pipe Mini-Lab according to steps 1,2,3, and 4 of Experiment A.
2. Perform steps 5,6,7,8, and 9 of Experiment A. Be sure to record all data.
3. Replace the 20" length by 1/2" diameter, water charged Heat Pipe with a 20" length by 1/2" diameter, methanol charged Heat Pipe.
4. All thermocouples should remain as for the water charged pipe.
5. Repeat steps 5,6,7,8, and 9 of Experiment A with the methanol charged pipe. Record all required temperatures and input wattages. Pay particular attention to the burn-out point.
6. Compare the results of Experiment A and Experiment D, especially the temperatures versus input wattages, and the burn-out point.

QUESTIONS

1. What capabilities makes a methanol charged Heat Pipe more desirable than a water charged Heat Pipe?
2. At a given range between 20°C. and 100°C, and prior to burn-out, which Heat Pipe transports more heat, the water charged or the methanol pipe?
3. Why would a water charged Heat Pipe have greater or lesser heat transporting capabilities than a methanol charged pipe?
4. Why would one use a methanol charged Heat Pipe in place of a water charged Heat Pipe?

5. Illustration of Isothermal Characteristics of Heat Pipes

When operated within their capacities Heat Pipes are isothermal over short lengths (6") and greater lengths (6'). For small diameter pipes the ΔT is approximately 2°C. per foot of length. If the pipe temperature is measured very near to the heater there will be some conduction heating along the walls of the pipe. Similarly, if the temperature is measured very close to the cooling fins there will be some conduction cooling. It is suggested, therefore, as in the foregoing experiments, that thermocouples be placed at least 3" from either the heater or the fins on 1/2" diameter Heat Pipes and at least 1 1/4" from either the heater or the fins on 3/8" diameter Heat Pipes.

Experiment E (Isothermal Characteristics)

1. Set up the Heat Pipe Mini-Lab according to steps 1,2,3, and 4 of Experiment A, except in lieu of the thermocouple attached to the heater assembly, connect a thermocouple to the Heat Pipe wall 3" from the heater assembly or another 3" from the dissipating fins.
2. Perform steps 5,6,7,8, and 9 of Experiment A. Be sure to record accurately the temperatures of both thermocouples and the input wattage.
3. Compare the difference in temperature along the Heat Pipe wall (as measured by the thermocouples) with increased power transport prior to burn-out.
4. Deactivate the heater and allow Heat Pipe to cool to near room temperature. Readjust the angle of the Heat Pipe so that the condenser section is now 3° above the evaporator section.
5. Reactivate the heater and repeat steps 5,6,7,8, and 9 of Experiment A. Again record all temperatures and power input wattages.

QUESTIONS

1. What effect does increase in heat transfer by the Heat Pipe have on its isothermal characteristics?
2. What is the ΔT of the Heat Pipe when transporting 100 watts of thermal energy?
3. What effect, if any, does attitude have on the isothermal characteristics of the Heat Pipe?
4. Can you think of any practical uses for the isothermal characteristics of the Heat Pipe?
5. How can the isothermal characteristics of the Heat Pipe be increased?

   (Refer to Section 5)

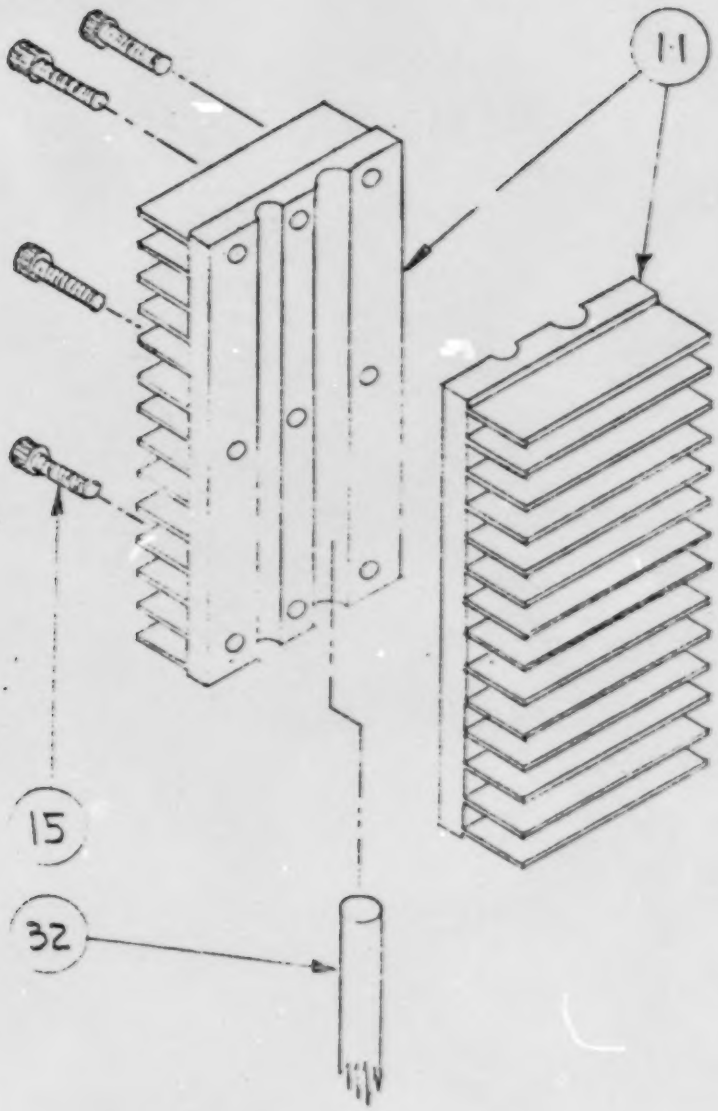


FIG I

83

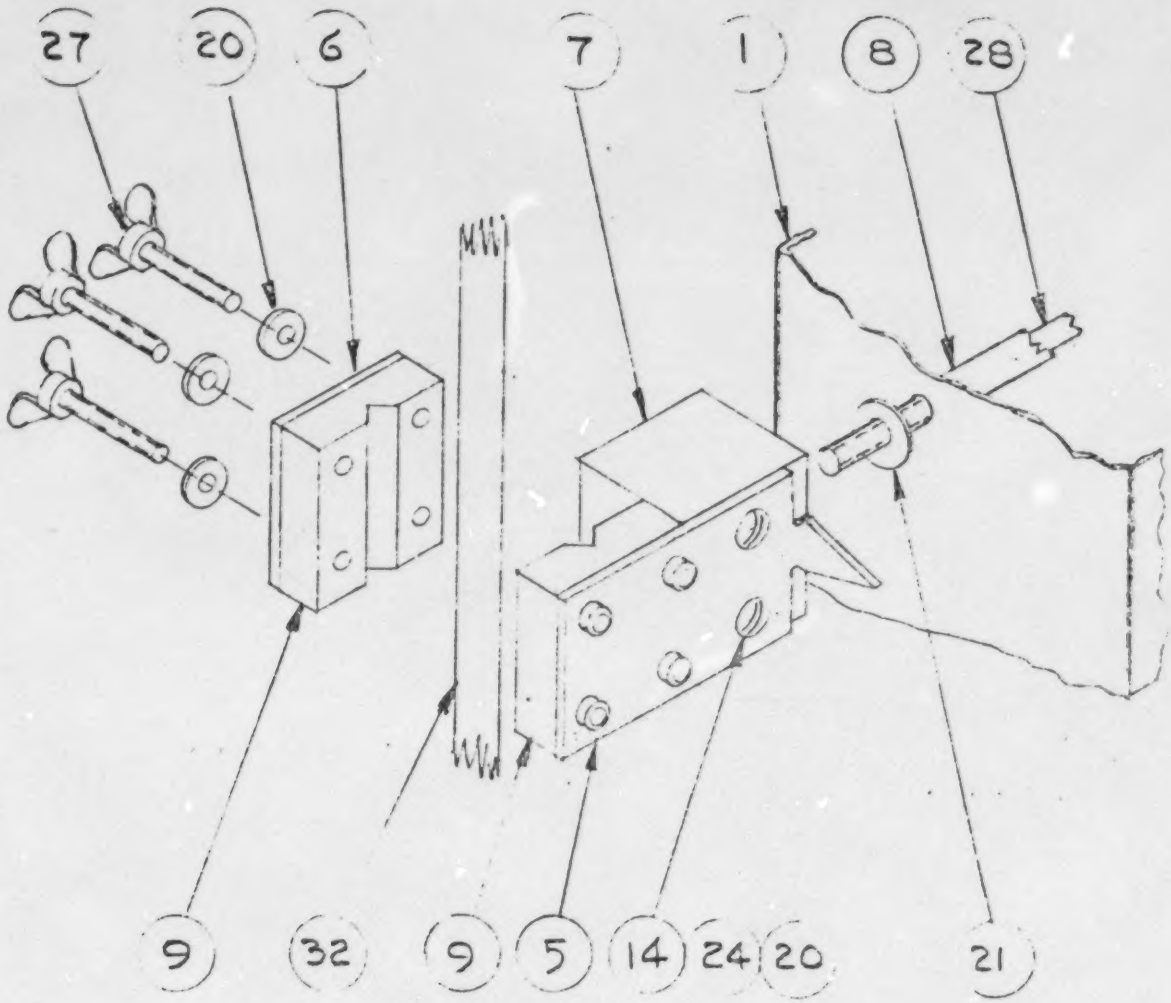


FIG II

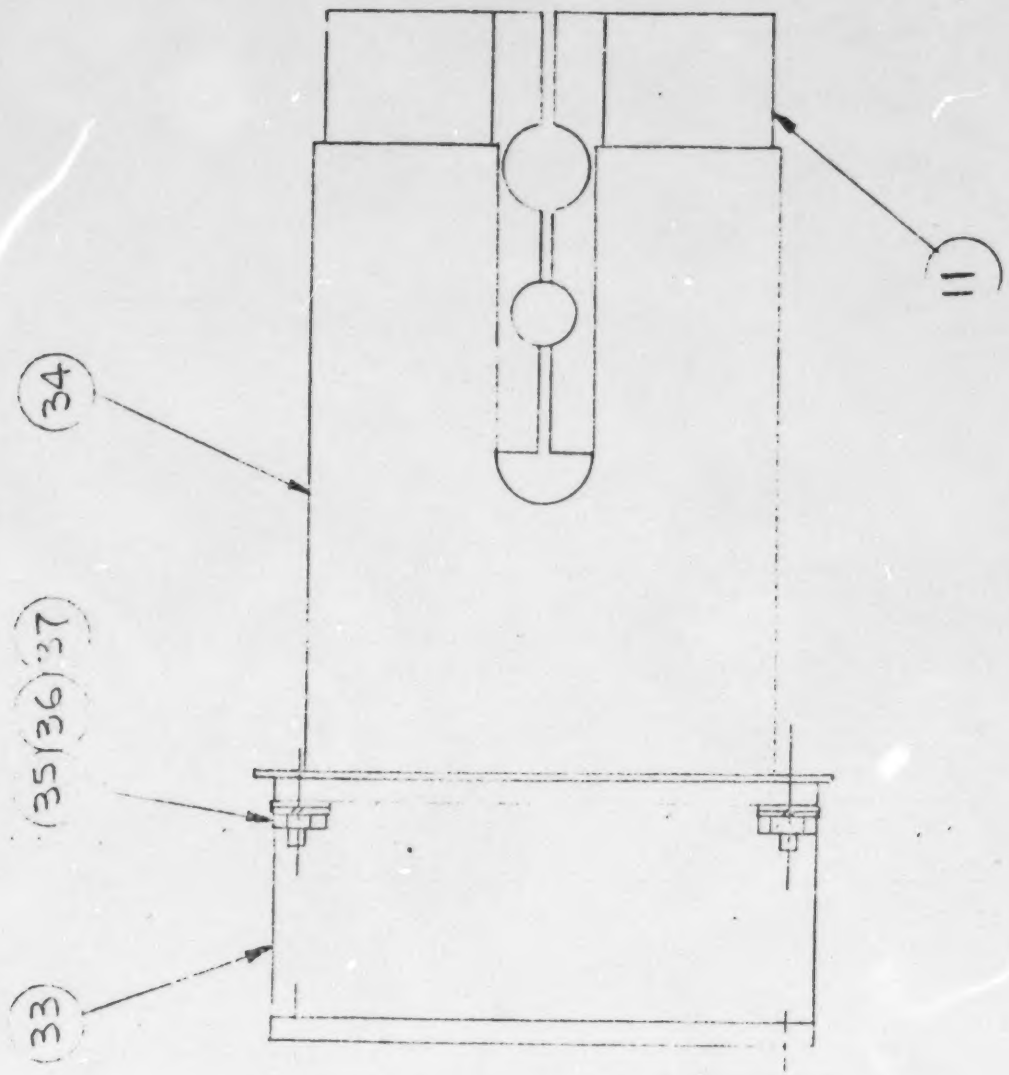


FIG III

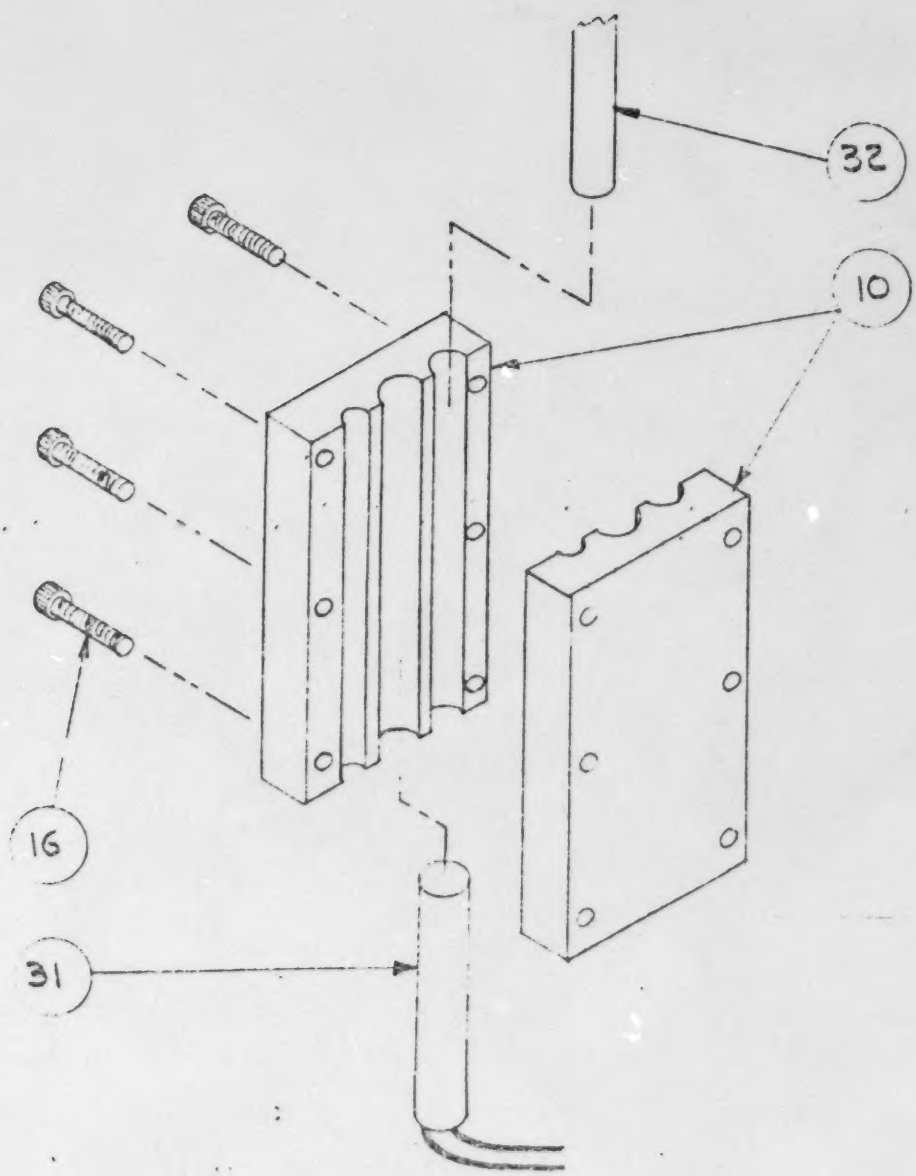


FIG. IV

```
100 PAGE
110 PRINT
120 PRINT
130 PRINT
140 PRINT
150 PRINT
160 PRINT "I        HEAT PIPE EXPERIMENT"
170 PRINT "I        ====================";
180 PRINT
190 PRINT
200 PRINT "     1. Allways use blower fan"
210 PRINT "     2. Use 100 watts of power input"
220 PRINT "     3. Do following experiments : A;B,C,D;F"
230 PRINT
240 PRINT "            A-1: Heat pipe attitude,evaporator is 15 "
250 PRINT "                 degrees below condenser"
260 PRINT "            A-2: Heat pipe attitude,evaporator is 15"
270 PRINT "                 degrees above condenser"
280 PRINT "            B  : Effect of heat pipe length, evaporator"
290 PRINT "                 is 15 degrees below condenser"
300 PRINT "            C  : Effects of diameter, evaporator is 15"
310 PRINT "                 degrees below condenser"
320 PRINT "            D  : Effects of working fluid, evaporator is"
330 PRINT "                 15degrees below condenser"
340 PRINT "            F  : Using copper rod"
350 PRINT
```

HEAT PIPE EXPERIMENT

1. Allways use blower fan
2. Use 100 watts of power input
3. Do following experiments : A,B,C,D,F

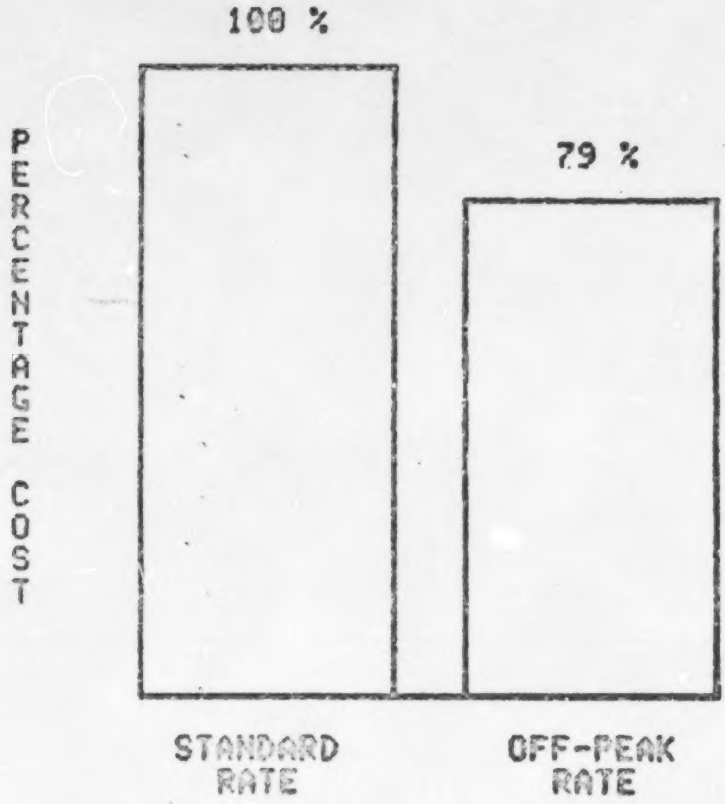
A-1: Heat pipe attitude, evaporator is 15 degrees below condenser
A-2: Heat pipe attitude, evaporator is 15 degrees above condenser
B : Effect of heat pipe length, evaporator is 15 degrees below condenser
C : Effects of diameter, evaporator is 15 degrees below condenser
D : Effects of working fluid, evaporator is 15degrees below condenser
F : Using copper rod

SOLAR ASSISTED HEAT PUMP
COOLING MODE

SOLAR ASSISTED HEAT PUMP - COOLING TEST
****

WATER FLOW RATE,(lbs/hr),	M5 = 200
COLD TANK CAPACITY,(lbs),	M6 = 800
ENTERING COIL TEMP,(F),	T5 = 40
LEAVING COIL TEMP,(F),	T6 = 30
INITIAL TANK TEMP,(F),	T7 = 40
FINAL TANK TEMP,(F),	T8 = 30
DURATION OF TEST,(hrs),	H5 = 2
HEAT PUMP WATTS,	W3 = 200
WATER PUMP WATTS,	W2 = 40
FAN WATTS,	W3 = 30
PEAK RATE,($/KW-HR),	R7 = .1
OFF-PEAK RATE,($/KW-HR),	R8 = .02
STANDARD RATE,($/KW-HR),	R9 = .06

COST COMPARISON OF COOLING SYSTEM USING OFF-PEAK ELECTRICAL RATE FOR 8-HOURS, PLUS STORAGE, VS STANDARD ELECTRICAL RATE FOR 24-HOURS, WITHOUT STORAGE



Note : EER (Energy Efficiency Ratio) is : 10.4 for either type of operation

```
100 PAGE
110 INIT
120 REM * INPUT DATA *
130 T$="SOLAR ASSISTED HEAT PUMP - COOLING TEST"
140 MOVE 65,90
150 PRINT "K";
160 FOR I=1 TO LEN(T$)/2
170 PRINT "H";
180 NEXT I
190 PRINT T$
200 MOVE 31,90
210 PRINT USING "39""*""":
220 PRINT
230 PRINT
240 PRINT
250 PRI "          WATER FLOW RATE,(lbs/hr),                M5 = ";
260 INPUT M5
270 PRINT
280 PRI "          COLD TANK CAPACITY,(lbs),                M6 = ";
290 INPUT M6
300 PRINT
310 PRI "          ENTERING COIL TEMP,(F),                  T5 = ";
320 INPUT T5
330 PRINT
340 PRI "          LEAVING COIL TEMP,(F),                   T6 = ";
350 INPUT T6
360 PRINT
370 PRI "          INITIAL TANK TEMP,(F),                   T7 = ";
380 INPUT T7
390 PRINT
400 PRI "          FINAL TANK TEMP,(F),                     T8 = ";
410 INPUT T8
420 PRINT
430 PRI "          DURATION OF TEST,(hrs),                  H3 = ";
```

```
440 INPUT H5
450 PRINT
460 PRI "          HEAT PUMP WATTS,                                    H5 = ";
470 INPUT W5
480 PRINT
490 PRI "          WATER PUMP WATTS,                                   W2 = ";
500 INPUT W2
510 PRINT
520 PRI "          FAN WATTS,                                          W3 = ";
530 INPUT W3
540 PRINT
550 PRI "          PEAK RATE,($/KW-HR),                                R7 = ";
560 INPUT R7
570 PRINT
580 PRI "          OFF-PEAK RATE,($/KW-HR),                            R8 = ";
590 INPUT R8
600 PRINT
610 PRI "          STANDARD RATE,($/KW-HR),                            R9 = ";
620 INPUT R9
630 PAGE
640 REM * Q5 : Chiller Capacity, (BTU/HR), *
650 Q5=H5*(T6-T5)+N6*(T7-T8)/H5
660 REM * C5 : Off- Peak Cost *
670 C5=(W5+W2+W3)*8*R8+(W2+W3)*16*R7
680 REM * C6 : Standard Cost *
690 C6=(W5/3+W2+W3)*24*R9
700 LET S1=C6/C6*100
710 LET S2=C5/C6*100
720 REM * E  : Energy Efficiency Ratio *
730 E=Q5/(W5+W2+W3)
740 MOVE 85,5
750 PRINT USING "2D.1D":E
760 A$="COST COMPARISON OF COOLING SYSTEM USING OFF-PEAK"
770 B$="ELECTRICAL RATE FOR 8-HOURS,PLUS STORAGE, VS"
780 C$="STANDARD ELECTRICAL RATE FOR 24-HOURS, WITHOUT STORAGE"
```

```
790 MOVE 63,93
800 PRINT "K";
810 FOR I=1 TO LEN(A$)/2
820 PRINT "U";
830 NEXT I
840 PRINT A$
850 MOVE 65,90
860 PRINT "K";
870 FOR I=1 TO LEN(B$)/2
880 PRINT "U";
890 NEXT I
900 PRINT B$
910 MOVE 65,87
920 PRINT "K";
930 FOR I=1 TO LEN(C$)/2
940 PRINT "U";
950 NEXT I
960 PRINT C$
970 REM * DRAW BAR GRAPH *
980 VIEWPORT 45,125,20,75
990 MOVE 0,0
1000 DRAW 80,0
1010 MOVE 0,0
1020 RDRAW 0,S1
1030 RDRAW 35,0
1040 RDRAW 0,-S1
1050 MOVE 45,0
1060 RDRAW 0,S2
1070 RDRAW 35,0
1080 RDRAW 0,-S2
1090 REM * LABEL HORIZONTAL AXIS *
1100 MOVE 3,0
1110 PRINT "JJ";
1120 PRINT USING 1130:"STANDARD","OFF-PEAK"
1130 IMAGE16A,16A
```

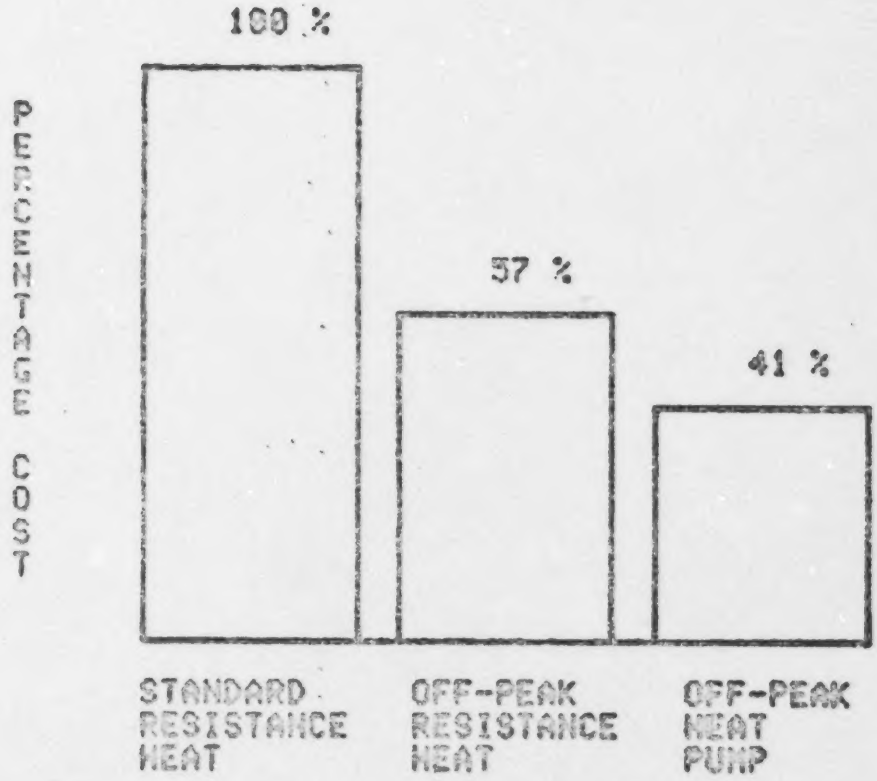
```
1140 MOVE 11,0
1150 PRINT "JJJ";
1160 PRINT USING 1170:"RATE","RATE"
1170 IMAGE16A,16A
1180 REM * LABEL VERTICAL AXIS *
1190 V$="PERCENTAGE COST"
1200 MOVE 0,50
1210 PRINT "RRRRRR";
1220 FOR I=1 TO LEN(V$)/2
1230 PRINT "K";
1240 NEXT I
1250 FOR I=1 TO LEN(V$)
1260 X$=SEG(V$,I,1)
1270 PRINT X$;"HJ";
1280 NEXT I
1290 MOVE 12,100
1300 PRINT "K";S1;" %"
1310 MOVE 59,52
1320 PRINT "K"
1330 PRINT "   %"
1340 MOVE 58,52
1350 PRINT "K";
1360 PRINT USING "2D":S2
1370 INIT
1380 WINDOW 0,130,0,100
1390 MOVE 10,5
1400 PRINT "Note : EER (Energy Efficiency Ratio) is :"
1410 MOVE 10,5
1420 PRINT "J";
1430 PRINT "       for either type of operation"
1440 HOME
1450 END
```

SOLAR ASSISTED HEAT PUMP
HEATING MODE

SOLAR ASSISTED HEAT PUMP - HEATING TEST
****

WATER FLOW RATE,(lbs/hr),	M1 = 200
TANK CAPACITY,(lbs),	M2 = 800
ENTERING COIL TEMP,(F),	T1 = 120
LEAVING COIL TEMP,(F),	T2 = 100
INITIAL TANK TEMP,(F),	T3 = 120
FINAL TANK TEMP,(F),	T4 = 115
HOURS OF TEST,	H = 2
STANDARD ELECTRIC RATE,($/KH-HR),	R9 = .06
OFF-PEAK ELECTRIC RATE,($/KH-HR),	R8 = .02
PEAK ELECTRIC RATE,($/KH-HR),	R7 = .1
WATTS INPUT TO HEAT PUMP,	W1 = 200
WATTS INPUT TO WATER CIRCULATOR,	W2 = 40
WATTS INPUT TO FAN,	W3 = 30

COST COMPARISON OF HEATING SYSTEM USING STANDARD RESISTANCE HEAT, OFF-PEAK RESISTANCE HEAT AND SOLAR ASSISTED HEAT PUMP SYSTEM



```
100 PAGE
110 INIT
120 REM  ** INPUT DATA **
130 T$="SOLAR ASSISTED HEAT PUMP - HEATING TEST"
140 MOVE 65,90
150 PRINT "K";
160 FOR I=1 TO LEN(T$)/2
170 PRINT "H";
180 NEXT I
190 PRINT T$
200 MOVE 31,90
210 PRINT USING "39""*""":
220 PRINT
230 PRINT
240 PRINT
250 PRI "          WATER FLOW RATE,(lbs/hr),                    M1 = ";
260 INPUT M1
270 PRINT
280 PRI "          TANK CAPACITY,(lbs),                         M2 = ";
290 INPUT M2
300 PRINT
310 PRI "          ENTERING COIL TEMP,(F),                      T1 = ";
320 INPUT T1
330 PRINT
340 PRI "          LEAVING COIL TEMP,(F),                       T2 = ";
350 INPUT T2
360 PRINT
370 PRI "          INITIAL TANK TEMP,(F),                       T3 = ";
380 INPUT T3
390 PRINT
400 PRI "          FINAL TANK TEMP,(F),                         T4 = ";
410 INPUT T4
420 PRINT
430 PRI "          HOURS OF TEST,                               H  = ";
```

```
440 INPUT H
450 PRINT
460 PRI "                STANDARD ELECTRIC RATE,($/KW-HR),          R9 = ";
470 INPUT R9
480 PRINT
490 PRI "                OFF-PEAK ELECTRIC RATE,($/KW-HR),          R8 = ";
500 INPUT R8
510 PRINT
520 PRI "                PEAK ELECTRIC RATE,($/KW-HR),              R7 = ";
530 INPUT R7
540 PRINT
550 PRI "                WATTS INPUT TO HEAT PUMP,                  W1 = ";
560 INPUT W1
570 PRINT
580 PRI "                WATTS INPUT TO WATER CIRCULATOR,           W2 = ";
590 INPUT W2
600 PRINT
610 PRI "                WATTS INPUT TO FAN,                        W3 = ";
620 INPUT W3
630 PAGE
640 REM  ** COMPUTATION **
650 REM *Q1:Heat Pump Effect*
660 Q1=W1*(T1-T2)+W2*(T4-T3)/H
670 REM *W9:Equivalent Resistance Watts*
680 W9=Q1/3.41
690 REM * C9:Equivalent Cost, Standard *
700 C9=((W9+W2+W3)*8+(W2+W3)*16)*R9
710 REM * C8:Equivalent Cost, Off-Peak *
720 C8=(W9+W2+W3)*8*R8+(W2+W3)*16*R7
730 REM * C7:"Actual" Cost, Heat Pump *
740 C7=(W1+W2+W3)*8*R8+(W2+W3)*16*R7
750 REM  ** DRAW BAR GRAPH **
760 VIEWPORT 35,130,20,70
770 MOVE 0,0
780 DRAW 83,0
```

```
790 GOSUB 810
800 GO TO 950
810 MOVE 0,0
820 RDRAW 0,C9/C9*100
830 RDRAW 25,0
840 RDRAW 0,-(C9/C9)*100
850 MOVE 30,0
860 RDRAW 0,C8/C9*100
870 RDRAW 25,0
880 RDRAW 0,-(C8/C9)*100
890 MOVE 60,0
900 RDRAW 0,C7/C9*100
910 RDRAW 25,0
920 RDRAW 0,-(C7/C9)*100
930 HOME
940 RETURN
950 REM
960 A$="COST COMPARISON OF HEATING"
970 MOVE 41,150
980 PRINT "K";
990 FOR I=1 TO LEN(A$)/2
1000 PRINT "H";
1010 NEXT I
1020 PRINT A$;
1030 B$="SYSTEM USING STANDARD RESISTANCE"
1040 MOVE 41,143
1050 PRINT "K";
1060 FOR I=1 TO LEN(B$)/2
1070 PRINT "H";
1080 NEXT I
1090 PRINT B$;
1100 C$="HEAT, OFF-PEAK RESISTANCE HEAT"
1110 MOVE 41,136
1120 PRINT "K";
1130 FOR I=1 TO LEN(C$)/2
```

```
1140 PRINT "H";
1150 NEXT I
1160 PRINT C$;
1170 D$="AND SOLAR ASSISTED HEAT PUMP SYSTEM"
1180 MOVE 41,129
1190 PRINT "K";
1200 FOR I=1 TO LEN(D$)/2
1210 PRINT "H";
1220 NEXT I
1230 PRINT D$;
1240 REM ** LABEL HORIZONTAL **
1250 MOVE 0,0
1260 PRINT "JJ";
1270 PRINT USING 1280:"STANDARD","OFF-PEAK","OFF-PEAK"
1280 IMAGE13A,13A,13A
1290 RMOVE 0,0
1300 PRINT "JJJ";
1310 PRINT "RESISTANCE   RESISTANCE   HEAT"
1320 RMOVE 0,0
1330 PRINT "JJJJ";
1340 PRINT "HEAT          HEAT          PUMP"
1350 VIEWPORT 35,130,20,70
1360 V$="PERCENTAGE COST"
1370 MOVE 0,50
1380 PRINT "HHHHHH";
1390 FOR I=1 TO LEN(V$)/2
1400 PRINT "K";
1410 NEXT I
1420 FOR I=1 TO LEN(V$)
1430 X$=SEG(V$,I,1)
1440 PRINT X$;"HJ";
1450 NEXT I
1460 MOVE 10,100
1470 PRINT "K";"100";" %"
1480 MOVE 41,C9/C9*100
```

```
1490 PRINT "K";
1500 PRINT "   %"
1510 MOVE 41,C8/C9*100
1520 PRINT "K";
1530 PRINT USING "2D":C8/C9*100
1540 MOVE 71,C7/C9*100
1550 PRINT "K";
1560 PRINT "   %"
1570 MOVE 71,C7/C9*100
1580 PRINT "K";
1590 PRINT USING "2D":C7/C9*100
1600 NONE
1610 END
```

AIR TO AIR SOLAR TRAINER

*

This is an AIR TO AIR SOLAR SIMULATOR lab. Instructions are quite simple to follow and will be given as we go along.

There are however some basic rules you must follow in order to compleate the experiment acurately, they are:

1 Be absolutly sure that your information is correct befor you press RETURN. Once you press RETURN your data will be stored in the computer for exicution and cannot be alterd. If you enter incorrect data accidently and have already pressed RETURN you may start again by pressing the BREAK key twice and then typing RUN.

2. When an asterix appears at the top left hand corner of the screen, you may make a hard copy of it by pressing the key marked MAKE COPY located in the upper right hand corner of the keyboard.

PRESS RETURN WHEN READY TO CONTINUE

Type in the rock storge temp (F) for each reading on your data sheet.

Please note that time is based on a 5 minute hour.

T I M E	T E M P (f)
8:00am	68
10:00am	69
12:00noon	74
2:00pm	78
4:00pm	85
6:00pm	95
8:00pm	90
10:00pm	88
12:00mid	86
2:00am	75
4:00am	65
6:00am	69
8:00am	70

S E C T I O N T W O

This section of the experiment deals with the heat energy relationships for the twenty-four period observed.

The equations used to draw the following graph are as follows:

C = (S(13) - S(1)) * 3.41-----SOLAR HEAT COLLECTED, Byu/day

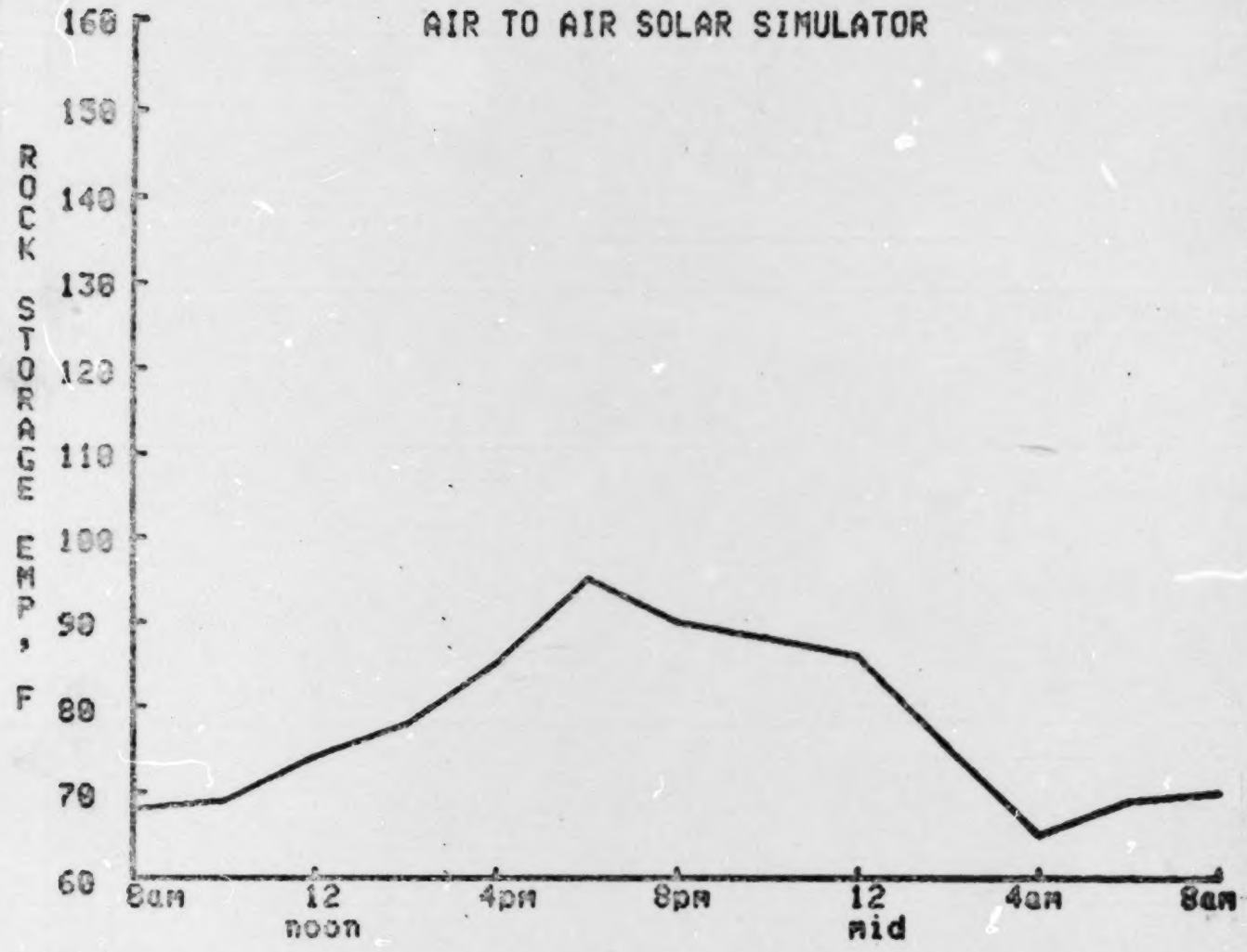
F = [K(13)-K(1)](3.14) RESISTANCE HEAT USED, Btu/day

Q = (58)[T(13)-T(1)] HEAT STORED, Btu/day

U = C + F - Q HEATING LOAD, Btu/day

Again I must stress that you type all your information correctly befor pressing the RETURN key

Now press the RETURN key and we'll get started


AIR TO AIR SOLAR SIMULATOR
ROCK STORAGE EMP, F
160
150
140
130
120
110
100
90
80
70
60
8am
12 noon
4pm
8pm
12 mid
4am
8am
TIME OF DAY

```
10 PAGE
20 INIT
30 MOVE 37,55
40 PRINT "-----AG IG RG    TG OG   AG IG RG------    "
50 MOVE 40,49
60 PRINT "----------SG OG LG AG RG----------"
70 MOVE 43,43
80 PRINT "----SG IG MG UG LG AG TG OG RG----"
90 FOR I=1 TO 10
100 MOVE 30,60
110 DRAW 30,39
120 DRAW 100,39
130 DRAW 100,60
140 DRAW 30,60
150 NEXT I
160 FOR I=1 TO 250
170 NEXT I
180 PAGE
190 FOR I=1 TO 5
200 PRINT
210 NEXT I
220 PRINT "This is an AIR TO AIR SOLAR SIMULATOR lab.  Instructions are"
230 PRINT
240 PRINT "quite simple to follow and will be given as we go along.  "
250 PRINT
260 PRINT
270 PRINT
280 PRINT "There are however some basic rules you must follow in order"
290 PRINT
300 PRINT "to complete the experiment acurately. They are:"
310 PRINT
320 PRINT
330 PRINT " I 1 Be absolutly sure that your information is correct"
340 PRINT " I   befor you press RETURN.  Once you press RETURN your"
```

```
350 PRINT " I   data will be stored in the computer for execution"
360 PRINT " I   and cannot be alterd.  If you enter incorrect data"
370 PRINT " I   accidently and have already pressed RETURN you may"
380 PRINT " I   start again by pressing the BREAK key twice and "
390 PRINT " I   then typing RUN.  "
400 FOR I=1 TO 3
410 PRINT
420 NEXT I
430 PRINT " I 2.When an asterisk appears at the top left hand corner"
440 PRINT " I   of the screen, you may make a hard copy of it by"
450 PRINT " I   pressing the key marked MAKE COPY located in the "
460 PRINT " I   upper right hand corner of the keyboard."
470 PRINT " I   ==========================="
480 FOR I=1 TO 90
490 HOME
500 PRINT " * "
510 MOVE 0,3
520 NEXT I
530 PRINT "PRESS RETURN WHEN READY TO CONTINUE"
540 POINTER A,B,C$
550 PAGE
560 INIT
570 WINDOW 0,12,60,160
580 VIEWPORT 20,120,20,100
590 DIM T(25)
600 PRINT "Type in the rock storge temp (F) for each reading on your "
610 PRINT "data sheet.  ";
620 PRINT
630 PRINT
640 PRINT "GGGGGGGGGGGGPlease note that time is based on a 5 ";
645 PRINT "minute hour.GGGGGGGGGGGGG"
650 PRINT
660 PRINT
```

```
690 PRINT "ßßß
```

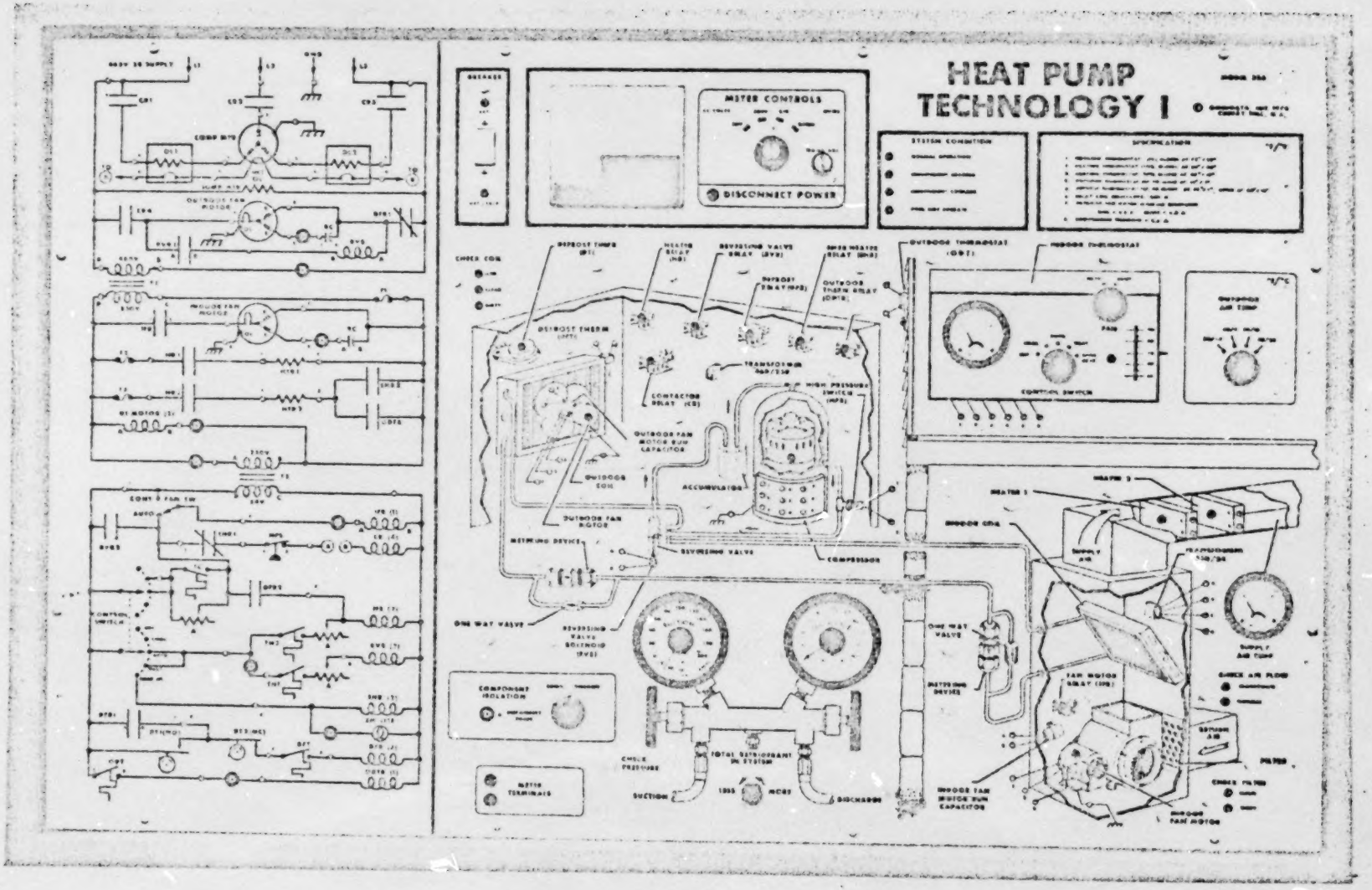
```
1040 PRINT "        noon                                    mid"
1050 R=168
1060 FOR G=168 TO 68 STEP -10
1070 R=R-10
1080 MOVE -1,R
1090 PRINT G
1100 NEXT G
1110 MOVE 3.5,45
1120 PRINT "T I M E    O F   D A Y"
1130 MOVE 0,0
1140 MOVE 0,T(1)
1150 FOR I=2 TO 13
1160 DRAW I-1,T(I)
1170 NEXT I
1180 DATA "8:00am","10:00am","12:00noon","2:00pm","4:00pm","6:00pm"
1190 DATA "8:00pm","10:00pm","12:00mid","2:00am","4:00am","6:00am"
1200 DATA "8:00am"
1210 HOME
1220 PRINT "GG*"
1230 POINTER A,B,C$
1240 PAGE
1250 PRINT " I GGGGGGGGGSG EG CG TG IG OG NG      TG WG OGGGGGGGG"
1260 FOR I=1 TO 5
1270 PRINT
1280 NEXT I
1290 PRINT " This section of the experiment deals with the heat energy"
1300 PRINT " relationships for the twenty-four period observed."
1310 PRINT
1320 PRINT
1330 PRINT " The equations used to draw the following graph"
1340 PRINT " are as follows:"
1350 FOR I=1 TO 3
1360 PRINT
1370 NEXT I
1380 PRINT "  C = ( S(13) - S(1) ) * 3.14 -----SOLAR HEAT COLLECTED,"
```

```
1385 PRINT "Btu/day"
1390 PRINT
1400 PRINT
1410 PRINT "  F = EK(13)-K(1)I(3.14)  RESISTANCE HEAT USED, Btu/day"
1420 PRINT
1430 PRINT
1440 PRINT "  Q = (58)ET(13)-T(1)I    HEAT STORED, Btu/day"
1450 PRINT
1460 PRINT
1470 PRINT "  U = C + F - Q          HEATING LOAD, Btu/day"
1480 FOR I=1 TO 3
1490 PRINT
1500 NEXT I
1510 PRINT "Again I must stress that you type all your information"
1520 PRINT "correctly befor pressing the RETURN key"
1530 PRINT
1540 PRINT "Now press the RETURN key and we'll get started"
1550 POINTER A,B,C$
1560 PAGE
1570 FOR I=1 TO 10
1580 PRINT
1590 NEXT I
1600 DIM K(13)
1610 PRI "     INPUT VOLTS,                                    E = ";
1620 INPUT E
1630 PRINT
1640 PRI "     INPUT AMPS,                                     I = ";
1650 INPUT I
1660 PRINT
1670 PRI "     INPUT INITIAL WATT-HOUR READING, W/hr          K(1)= ";
1680 INPUT K(1)
1690 PRINT
1700 PRI "     INPUT FINAL WATT-HOUR READING, W/hr            K(13)= ";
1710 INPUT K(13)
1720 PRINT
```

```
1730 PAGE
1740 C=8*E*I*3.14
1750 F=(K(13)-K(1))*3.14
1760 Q=58*(T(13)-T(1))
1770 U=C+F-Q
1780 PRINT "                                  AIR TO AIR SOLAR SIMULATOR"
1790 PRINT "                                  ENERGY RELATIONSHIP GRAPHS"
1800 PRINT "                                  ==========================="
1810 WINDOW 0,130,0,45000
1820 VIEWPORT 0,130,20,100
1830 MOVE 20,0
1840 DRAW 20,C
1850 DRAW 40,C
1860 DRAW 40,0
1870 DRAW 20,0
1880 X1=ABS(F)
1890 X2=ABS(Q)
1900 X3=ABS(U)
1910 MOVE 45,0
1920 DRAW 45,X1
1930 DRAW 65,X1
1940 DRAW 65,0
1950 DRAW 45,0
1960 MOVE 70,0
1970 DRAW 70,X2
1980 DRAW 90,X2
1990 DRAW 90,0
2000 DRAW 70,0
2010 MOVE 95,0
2020 DRAW 95,X3
2030 DRAW 115,X3
2040 DRAW 115,0
2050 DRAW 95,0
2060 MOVE 15,0
2070 PRINT "JJ";"   SOLAR HEAT     AUXILLARY     SOLAR HEAT     HEATING?
```

```
2080 MOVE 15,0
2090 PRINT "JJJ";"   COLLECTED          HEAT          STORED          LOAD"
2100 MOVE 15,0
2110 PRINT "JJJJ";"     Btu/day         Btu/day       Btu/day";
2120 PRINT "          Btu/day"
2130 Z1=INT(C)
2140 Z2=INT(F)
2150 Z3=INT(Q)
2160 Z4=INT(U)
2170 MOVE 20,C
2180 PRINT "K";"    ";Z1
2190 MOVE 45,X1
2200 PRINT "K";"    ";Z2
2210 MOVE 70,X2
2220 PRINT "K";"    ";Z3
2230 MOVE 95,X3
2240 PRINT "K";"    ";Z4
2250 PRINT "GGGGGGGGGG"
2260 HOME
2270 END
```

HEAT PUMP TECHNOLOGY


HEAT PUMP
TECHNOLOGY I
METER CONTROLS
DISCONNECT POWER

BRIEF THEORY REVIEW OF THE SIMULATED SYSTEM

A heat pump is a device capable of moving hea from one location to another. An air conditioner is an example of a heat pump. General use of the term "heat pump" means however a reversible air conditioner. A more precise term is a reverse cycle heat pump. Because heat pumps are reliable and reasonably priced, they have become a popular means of heating and cooling homes. As the price of oil and gas has increased in recent years, the heat pump, which operates with electricity, has become a competitive source of home heating. Some areas now have banned the use of gas to heat new homes and oil supplies have become less dependable. Thus the sudden surge to heat pumps. Heat pumps are more complicated than electric resistance heaters and much more costly to install. Over a useful life of ten years however, the more efficient heat pump easily pays for itself. It does this in two ways. First, it generally transfers two to three times more heat energy than the electric energy it consumes. Secondly, it's an air conditioner in the summer time. Since many people install air conditioning in addition to a heating system, this feature makes the heat pump even more attractive.

Now let's examine how it works. The heat pump system consists of five major parts i.e. a pump, an outdoor coil, a metering device, an indoor coil and controls. Since we are considering a reverse cycle heat pump, a method of reversing operation is also required. This is contained in the controls and with a sixth part, a reversing solenoid valve. The reversing solenoid valve is easier and less expensive to build than a reversing pump. It effectively reverses the pump by switching the pump's input and output lines. Also, since the indoor and outdoor coils could be a distance apart, often two metering devices (or control orifices or expansion valves) are used, one by each coil. The use of two metering devices then requires a check valve across each device so that each is by-passed when the refrigerant flow is reversed compared to when that metering device is used. Within these

parts a common medium called a refrigerant is pumped in one direction to bring heat into the controlled space and pumped in the other direction to remove heat from the controlled space. A common refrigerant used is R-22. Of the many refrigerants available, R-22 has the pressure-temperature relationship which best fits the temperature ranges for which many systems are designed.

In the air conditioning cycle, the hot gas coming out of the compressor is directed by the reversing solenoid valve to the outdoor coil. The outdoor coil is a large finned coil that has an electric fan (outdoor fan motor) blowing the outside air across it. As the refrigerant is pumped through the outdoor coil, it gives up heat to the outside air and becomes a liquid. Remember, it is still under pressure from the compressor. As the refrigerant loses its heat to the outside air, the outside air is made hotter. Energy has been transferred from the refrigerant to the outside air. The condensed refrigerant is now a liquid under high pressure. The refrigerant bypasses the outdoor metering device by means of a check valve and proceeds to the indoor coil. Before the refrigerant enters the indoor coil it must go through the indoor metering device. After the refrigerant passes through the indoor metering device it enters the indoor coil. The pressure in the indoor coil is low because it is connected to the suction side of the compressor. As the refrigerant travels through the indoor coil heat supplied to the refrigerant liquid causes it to evaporate and again become a gas. The source providing this heat is the indoor air which is being blown over the indoor coil by the indoor fan motor. As the house air heats up the refrigerant, it becomes cooler itself. Energy in the form of heat is transferred from the house air to the refrigerant. The cooled house air is then blown back through the house. The warmed refrigerant is then drawn back into the compressor and the whole sequence starts over again.

In the heating cycle, the hot gas coming out of the compressor is direct to the indoor coil by the reversing solenoid valve. The indoor coil is a large finned coil that has an electrically driven fan (indoor fan) blowing indoor air across it. As the hot refrigerant gas is pumped through the indoor coil, it is cooled by the indoor air and becomes a liquid. Remember, the refrigerant is still under high pressure from the compressor. The refrigerant loses some of its heat to the indoor air which is made hotter. The condensed refrigerant is now a liquid under high pressure. From the indoor coil the condensed refrigerant bypasses the indoor metering device by means of a check valve and proceeds to the outdoor coil. Before the refrigerant enters the outdoor coil it must pass through the outdoor metering device. The pressure on the other side of the outdoor metering device is low because the outdoor coil is connected to the suction side of the compressor. The outdoor coil has an electrically driven fan (outdoor fan) blowing outdoor air across it. As the refrigerant gas travels through the outdoor coil, it is heated by the outdoor air and becomes a gas. This is how the heat from the outdoor air is transferred to the refrigerant. The low pressure refrigerant in the gas state is drawn back to the compressor and the whole sequence starts again.

The Reverse Cycle Heat Pump consists of four major subsystems plus the required power wiring. These subsystems are:

Indoor Air Handling
Outdoor Air Handling
Refrigerant Handling
Control

During Normal Operation in the cooling mode, the indoor air handling subsystem adds heat to the refrigerant via the indoor coil (evaporator), and the outdoor air handling subsystem

extracts heat from the refrigerant via the outdoor coil (condenser). In the heating mode, this operation is reversed. The indoor coil functions as the condenser, with the outdoor coil serving as the evaporator. The Indoor Air Handling subsystem includes aux heaters that operate if outdoor ambient conditions prevent the Heat Pump from maintaining the temperature called for by the Indoor thermostat (70°F). In conjunction with the metering device, the compressor causes the refrigerant to: flow and move the excess heat, condense and give off heat at the condenser, and evaporate and absorb heat at the evaporator.

Indoor Air Handling. - The indoor air handling subsystem consists of:

Blower (plus motor and belt)
Air Filter
Indoor Coil with metering device
Aux. Heaters
Air Handling Cabinet (and Ductwork)

This subsystem serves to circulate the indoor air and expose that air to the effects of the indoor coil. It is a simple subsystem whose primary operation is obvious. Less obvious are the effects of blower defects and air flow restriction. In the cooling mode, these malfunctions reduce the heat added to the refrigerant in the indoor coil (evaporator). The refrigerant system "cools down", and pressures decrease. In the heating mode, the effects are quite different. These malfunctions reduce the heat extracted from the refrigerant in the indoor coil (condenser). The refrigerant system "heats up", pressures increase, and eventually the HPS interrupts the Contactor Relay circuit. The refrigerant system is disabled until the HPS closes. The heat pump "cycles on and off" under control of the HPS as a result of insufficient air flow or no air flow through the indoor air handling system in the heating mode.

The Indoor Air Handling system also contains aux. heaters in line with the indoor coil. These heaters will function as needed to increase the Supply Air Temperature and maintain Indoor Air Temp as commanded by the Indoor Thermostat.

Outdoor Air Handling - The outdoor air handling subsystem consists of:

Outdoor Fan (and motor)
Outdoor Coil with metering device
Defrost Thermostat
Air Handling Cabinet

This subsystem serves to move outdoor air past the outdoor coil and expose that air to the effects of the outdoor coil. Much like the indoor air handling subsystem, its primary operation is obvious, but the secondary effects of its malfunction is less obvious. In the heating mode, fan defects and air flow restrictions reduce the amount of heat added to the refrigerant in the outdoor coil (evaporator). The refrigerant system "cools down", and pressures decrease. In the cooling mode, the effects are quite different. These malfunctions reduce the amount of heat extracted from the refrigerant in the outdoor coil (condenser). The refrigerant system "heats up", pressures increase, and eventually the HPS interrupts the Contactor Relay circuit. The refrigerant system is disabled until the HPS closes. The Heat Pump "cycles on and off" under control of the HPS as a result of insufficient air flow or no air flow through the outdoor air handling system in the cooling mode.

The Defrost Thermostat prevents excessive icing of the outdoor coil. In the heating mode, this coil is the evaporator and subject to very low temperatures. The defrost thermostat measures the temperature of this coil and closes at 35°F. When the Defrost Timer motor advances to the stage of entering the defrost

cycle, this thermostat determines whether or not the cycle will continue. If the coil is below 35°, the cycle is allowed to continue. Power to the Reversing Valve solenoid and the outdoor fan motor is interrupted. The Dishcarge (hot) Refrigerant gas is diverted to the outdoor coil. Without the outside air being blown over the coil, the coil warms and the ice melts. As soon as the ice is completely melted, the temperature of the coil rises rapidly and the outdoor thermostat opens ending the Defrost cycle by interrupting the power to the relay coil. This relay had been in self hold by its contacts. Should there be so much ice that it is not all melted within the allowed time (usually 10 minutes in an actual unit) the Defrost Timer will continue running and interrupt the power to the relay coil.

Refrigerant Handling - The refirgerant handling system consists of:

Compressor
HPS
Reversing Valve
Indoor Coil and Metering Device with one-way valve
Outdoor Coil and Metering Device with one-way valve
Accumulator
Refrigerant Plumbing

This subsystem serves to absorb heat at the evaporator, and transfer the heat to the condenser. In the cooling mode, the indoor coil is the evaporator, and the outdoor coil is the condenser. In the heating mode, the opposite is true. The indoor coil is the consenser, and the outdoor coil is the evaporator. In operation, high pressure refrigerant gas from the compressor discharge is routed past the HPS to the Reversing valve, which directs this hot gas to one of the coils. The position of the reversing valve depends on whether the indoor air temperature is

above or below the thermostat setting. If heat is needed, the valve directs this high pressure refrigerant to the indoor coil (condenser). If cooling is needed, the valve directs this hot gas to the outdoor coil. At the condenser coil, the refrigerant gas is liquified, giving off heat.

The HPS is a safety device which disengages the system if the compressor discharge pressure exceeds 370 PSIG.

Cooled liquid refrigerant flows to, then through the metering device (which is a flow restrictor) into the low pressure portion of the refrigerant circuit. The abrupt pressure reduction causes "Flash Bubbles" to appear and further cool the liquid which then enters the evaporator. Liquid refrigerant vaporizes in the low pressure environment of the evaporator by absorbing heat. Refrigerant in gas form from the evaporator output is routed through the reversing valve again, to the accumulator. The accumulator separates any liquid from this gas, which will then enter the compressor on the suction side.

Control - The control subsystem consists of:

- Low Voltage Transformer
- Indoor Control Unit
- Indoor Fan Relay
- HPS
- Heater Relay
- Reversing Valve Relay
- Emergency Heater Relay
- Defrost Relay
- Outdoor Thermostat Relay
- Defrost Thermostat
- Outdoor Thermostat

230 VAC is converted to the control subsystem operating voltage of 24 VAC by transformer T2. When the Fan switch is in CONT,

the indoor fan relay is energized and its closed contact applies line voltage to the indoor fan motor and the blower runs continuously. When the fan switch is set to AUTO, the blower operates under control of the thermostat and the control switch. Except when preempted by the HPS, the compressor overload thermal switches, or the Emergency Heat Relay, the Contactor Relay is energized whenever the Thermostat is closed, the control switch is in Cool, Auto or Heat, or the reversing valve relay is energized. Closed contacts of the Contactor Relay apply line voltage to the Compressor Motor and Outdoor Fan Motor. During normal operation the discharge pressure should never exceed 370 PSIG. Pressures beyond this limit would occur as a result of a wide variety of malfunctions, and could result in equipment damage. The HPS continuously monitors the discharge pressure, and interrupts the power to the Contactor Relay if the limit is passed. The refrigerand handling subsystem is this disabled to avoid damage to the equipment.

The Heater Relay is energized if the Heating Thermostat (TH2) is closed and the control switch is in the AUTO or HEAT position. Closed contacts of this relay apply line voltage to one or more of the Aux Heaters, depending on Outdoor Air Temperature.

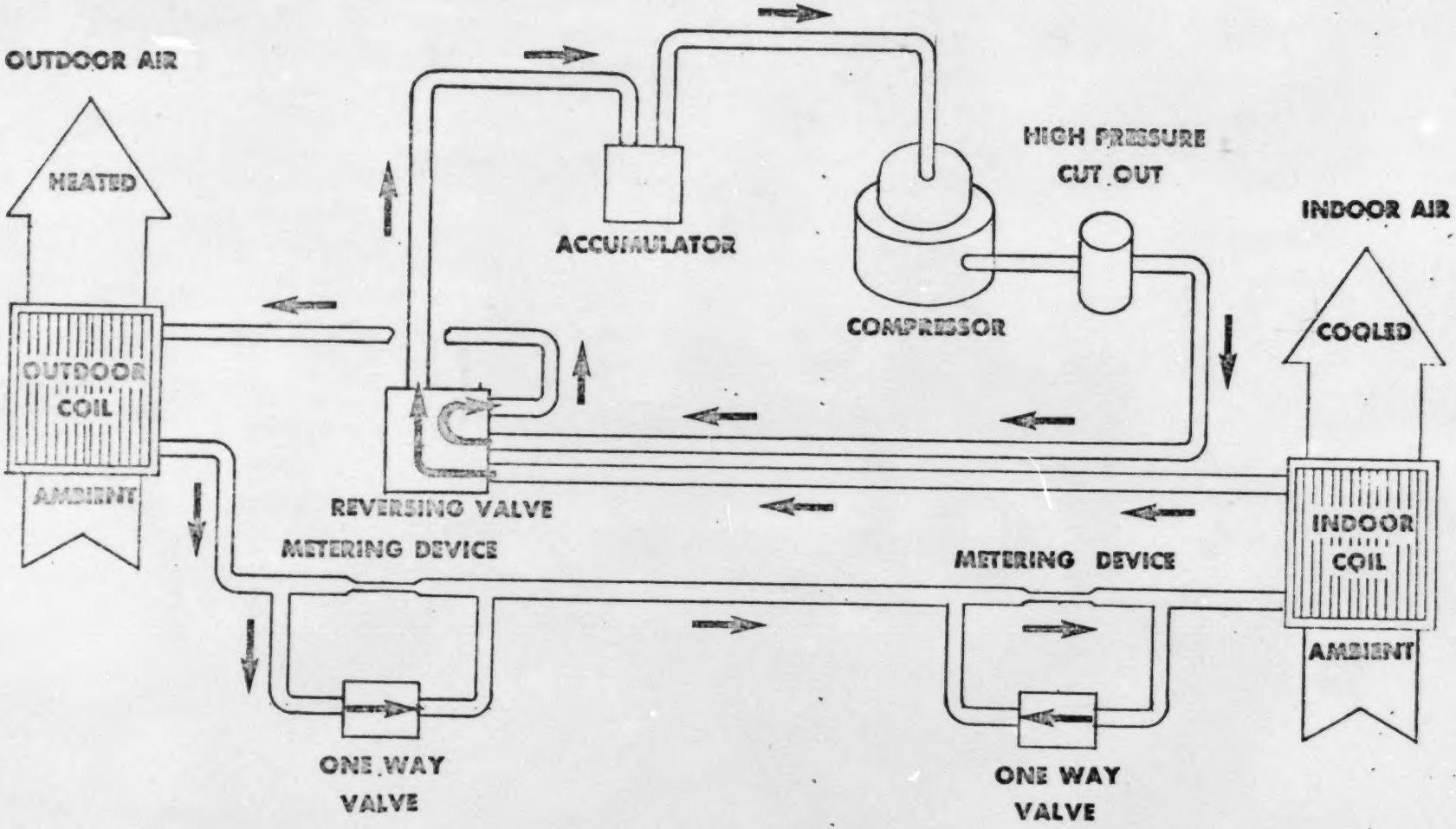
The Reversing Valve Relay is energized if the Heating Thermostat (TH1) is closed and the Control Switch is in the AUTO or HEAT positions. The closed contacts of this relay apply control voltage to the Contactor Relay, unless interrupted by the HPS, the compressor overload thermal switches or the Emergency Heat Relay.

The Emergency Heat Relay is energized if the Control Switch is in the EMER HT position. This relay has 2 sets of contacts, one normally closed. When this relay is energized, one set of contacts open and interrupt control voltage to the Contactor Relay,

disabling the refrigerant handling system. The other set of contacts closes, allowing the aux heaters to operate if the Heating Thermostat (TH2) and the Heater Relay so command.

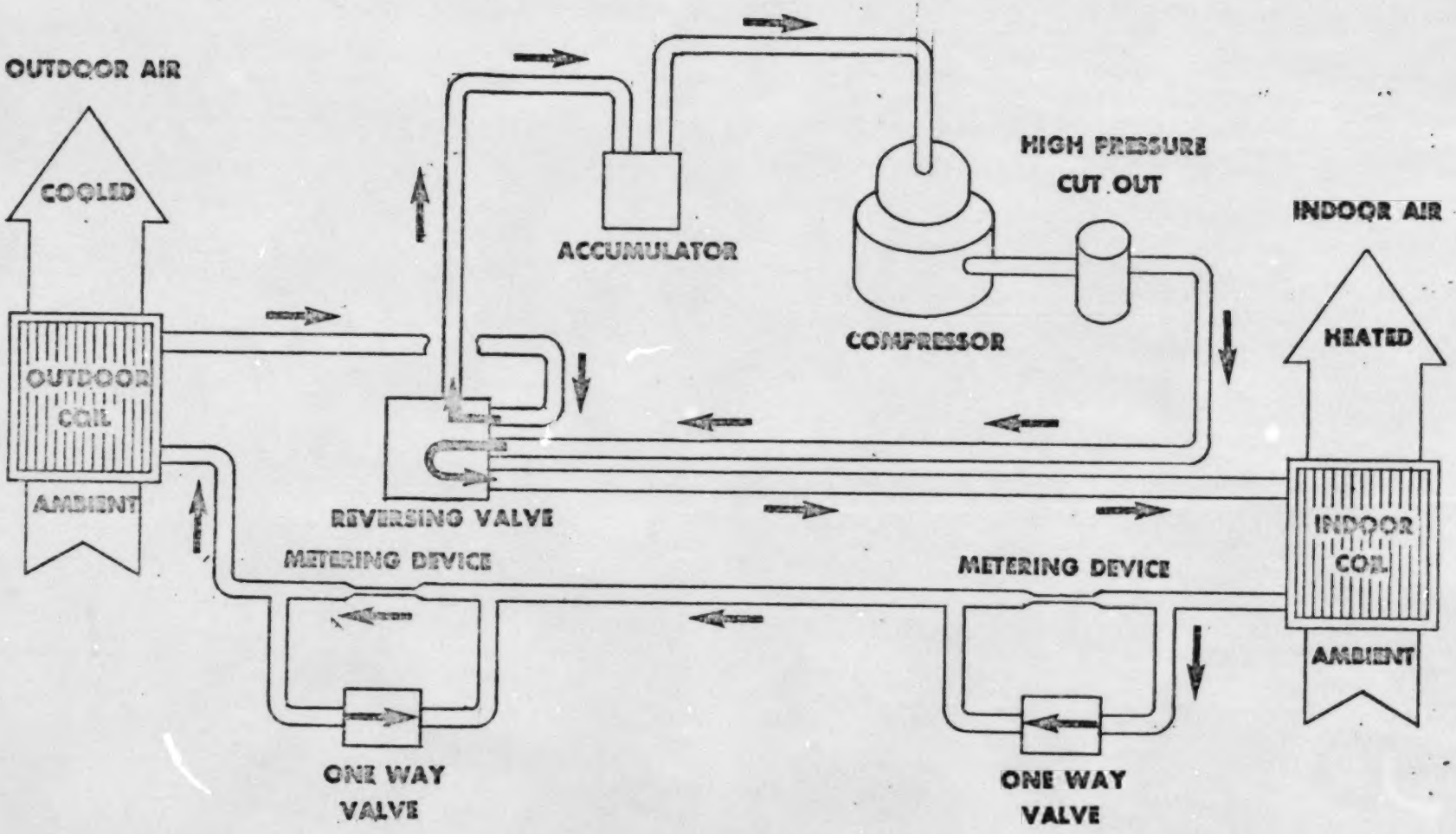
The Defrost Relay is energized when the Defrost Timer motor advances to the Defrost Cycle stage if the Defrost Thermostat is closed. This relay has 3 sets of contacts, one normally closed. When the relay is energized, the normally closed contacts open and interrupt line voltage to the Outdoor Fan Motor and the Reversing Valve solenoid, allowing Hot, High pressure refrigerant gas to be directed to the outdoor coil. When all ice is melted from this coil, the temperature of the coil rises rapidly causing the defrost thermostat to open interrupting power to the Defrost Relay, and the Defrost Cycle is over.

The Outdoor Thermostat Relay is energized when the Outdoor Thermostat is closed. This occurs when the temperature of the outdoor coil drops below 35°F. This will happen if either the outdoor temperature is below 35° or if the outdoor temperature is below 50°F and the heat pump is running. This latter case is due to the cooling of the outdoor coil by the evaporation of the refrigerated gas in the outdoor coil. If the Outdoor Thermostat contact is closed, the Outdoor Thermostat Relay is energized and allows the aux heaters to operate if the Heating Thermostat (TH2) and the Heater Relay so command.



4-10

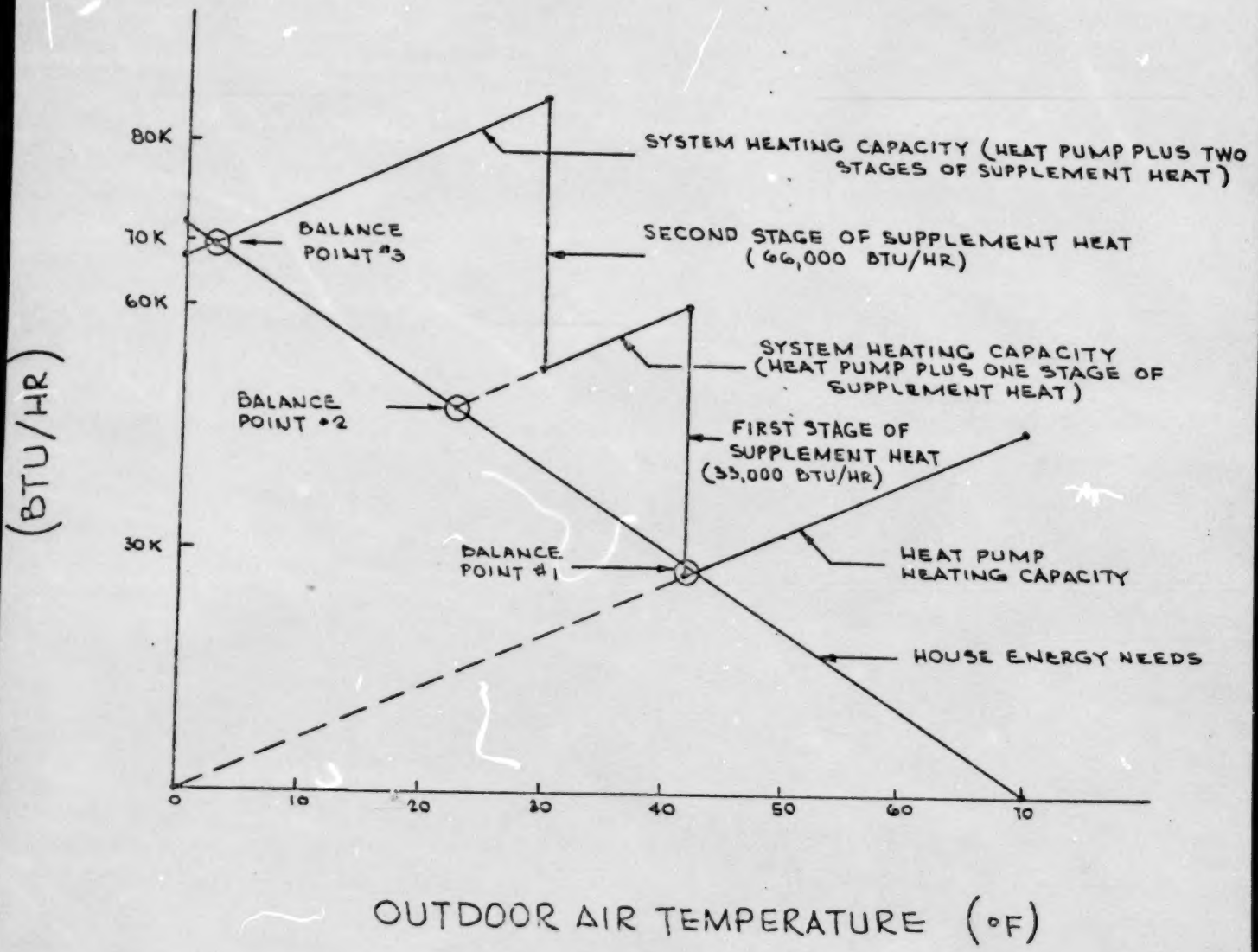
COOLING CYCLE



4-11

HEATING CYCLE

The graph indicates a house energy need of 70,000 BTU/hr at 0°F Outdoor Air Temp (OAT). This need becomes 0 BTU/hr at 70°F OAT. These two points are connected by a straight line which indicates house energy needs at any intermediate OAT. The other line represents the heating capacity of the simulated heat pump at OAT ranging from 70°F to 0°F. The point at which these lines cross is the "balance point", approximately 42°F in this case. At any temperature below this "balance point", the Heat Pump will be unable to completely satisfy the demand for heat (House Energy Needs). At balance point #1, the indoor thermostat connects the first resistance heater (HTR-1) into the heating system in such a way that as the Heat Pump fails to keep up the demand, the indoor temperature drops an additional 2°F. Heating Thermostat TH2 closes, and Heater HTR-1 is turned on. This adds approximately 9,600 KW or 33,000 BTU/hr to the heating capability of the system. Now the system will cycle around the lower thermostat setting, cutting HTR-1 on and off in a manner such as to maintain the Indoor Temperature. As the outdoor temperature decreases further, the heating requirements increase as the capabilities of the heat pump decrease. Just above a point where the demands and capabilities are equal (balance point #2) a second electric resistance heater (HTR-2) is connected in paralled to HTR-1 by the outdoor thermostat. Again the system will cycle around the lower thermostat setting, turning both HTR-1 and HTR-2 on and off such as to maintain Indoor Air Temperature. As the outdoor temperature drops still further, the "on" time of HTR-1 and HTR-2 will become greater until balance point #3 is reached. Below this temperature the heating system cannot keep up with the demand and the indoor temperature will drop as a function of the outdoor temperature. (See graph on following page).


80K
70K
60K
30K
(BTU/HR)
SYSTEM HEATING CAPACITY (HEAT PUMP PLUS TWO STAGES OF SUPPLEMENT HEAT)
BALANCE POINT #3
SECOND STAGE OF SUPPLEMENT HEAT (66,000 BTU/HR)
SYSTEM HEATING CAPACITY (HEAT PUMP PLUS ONE STAGE OF SUPPLEMENT HEAT)
BALANCE POINT #2
FIRST STAGE OF SUPPLEMENT HEAT (33,000 BTU/HR)
BALANCE POINT #1
HEAT PUMP HEATING CAPACITY
HOUSE ENERGY NEEDS
0
10
20
30
40
50
60
70
OUTDOOR AIR TEMPERATURE (°F)

REFRIGERANT PRESSURES

Condition	Temperature	Suction (PSIG)	Discharge (PSIG)	Mode
Running	20°/°-7	30	195	Heating
Running	40°/°4	50	225	Heating
Running	60°/°15	62	245	Heating
Running	80°/°26	70	260	Cooling
OFF	20°/°-7	43	43	Heating
OFF	40°/°4	69	69	Heating
OFF	60°/°15	103	103	Heating
OFF	80°/°26	145	145	Cooling

TYPICAL VALUES FOR HEAT PUMP PARTS

1) Compressor Motor
   A) All Windings = 0.5 ohms

2) Outdoor Fan Motor
   A) Start Winding = 6.0 ohms
   B) Run Winding = 2.0 ohms

3) Indoor Fan Motor
   A) Start Winding = 6.0 ohms
   B) Run Winding = 2.0 ohms

4) High Voltage Transformer (T1)
   A) Primary = 50 ohms
   B) Secondary = 0.2 ohms

5) Low Voltage Transformer (T2)
   A) Primary = 50 ohms
   B) Secondary = 0.2 ohms

6) Defrost Timer Motor = 4,000 ohms

7) Electric Strip Heaters
   A) Heater No. 1 = 9 ohms
   B) Heater No. 2 = 9 ohms

8) All Relay Coils = 75 ohms

PRACTICE EXERCISE

THE PRESSURE GAUGES

What are the pressures with the heat pump off?

20°F - Suction?_____ Discharge?_____

40°F - Suction?_____ Discharge?_____

60°F - Suction?_____ Discharge?_____

80°F - Suction?_____ Discharge?_____

What are the pressures with the heat pump running normally?

20°F - Suction?_____ Dishcarge?_____ Heating

40°F - Suction?_____ Discharge?_____ Heating

60°F - Suction?_____ Discharge?_____ Heating

80°F - Suction?_____ Discharge?_____ Cooling

What are the pressures with problem #6 inserted?

20°F - Suction?_____ Discharge?_____

Why?_____

_____

40°F - Suction?_____ Discharge?_____

Why?_____

_____

60°F - Suction?_____ Discharge?_____

Why?_____

_____

80°F - Suction?_____ Discharge?_____

Why?_____

_____

What are the pressures with problem #20 inserted?

20°F - Suction?_____ Discharge?_____

Why?_____

_____

40°F - Suction?_____ Discharge?_____

Why?_____

_____

60°F - Suction?_____ Discharge?_____

Why?_____

_____

80°F - Suction?_____ Discharge?_____

Why?_____

What happens if we increase the refrigerant charge with the compressor off?_____

_____

Why?_____

_____

_____

PRACTICE EXERCISE

THE MULTI-METER

What is the voltage beyween any one of the three supply lines and ground?_____

What is the voltage between any two of the three supply lines?

_____

What is the voltage across the primary of Transformer T1?_____

_____

What is the voltage across the secondary of Transformer T1?_____

_____

What is the voltage across the primary of Transformer T2?_____

_____

What is the voltage across the secondary of Transformer T2?_____

_____

What is the voltage across the HPS with problem #6 inserted and Outdoor Air Temp at 40°F?_____

Why?_____

_____

What is the voltage across the contactor relay coil with problem #6 inserted and Outdoor Air Temp at 40°F?_____

Why?_____

What is the resistance of Indoor fan motor start winding?_____

_____

What is the resistance of Indoor fan motor run winding?_____

_____

What is the resistance of these two windings in series?_____

_____

What is the resistance of the contactor relay coil with the Heat Pump running?_____

DOMESTIC HOT WATER,
SOLAR

DOMESTIC HOT WATER
COMPARISON OF SOLAR VS. ELECTRIC ENERGY USAGE ON181113100

TIME	BTU'S COLLECTED									INSO-LATION	ELEC. ENERGY	WATER	% BTU BY SOLAR	TOTAL
	GRUMMAN			HONEYCOMB			GE							
	BTU	BTU/SF	%	BTU	BTU/SF	%	BTU	BTU/SF	%	BTU/SF	BTU'S	GAL		BTU'S
11	143	3	43	330	20	100	0	0	0	86.71	1022.7	-78	31.6	1496.4

DOMESTIC HOT WATER
COMPARISON OF SOLAR VS. ELECTRIC ENERGY USAGE ON181114109

TIME	BTU'S COLLECTED									INSO-LATION	ELEC. ENERGY	WATER	% BTU BY SOLAR	TOTAL
	GRUMMAN			HONEYCOMB			GE							
	BTU	BTU/SF	%	BTU	BTU/SF	%	BTU	BTU/SF	%	BTU/SF	BTU'S	GAL		BTU'S
11	91	2	86091		0	100	0	0	0	17.44	511.3	0	15.3	603.9

samples of computer printout from Teletype Mod.43

```
100 REM THIS IS THE INITIALIZING ROUTINE
110 REM IT ALLOWS SETTING OF TIME AND PROVIDES
120 REM THE FIRST VALUE TO THE WATER METER INTERFACE
130 REM NO PROVISIN PRESENTLY EXISTS FOR POWER
140 REM FAILURE DETECT
150 G1=0
160 L=0
170 F1=0
180 M=0
190 N=0
200 F=0
210 U1=0
220 DIM X1(5)
230 DIM U(6)
240 G=0
245 S1=0
246 S2=0
250 DIM X(5)
260 FOR T=1 TO 5
270 X(T)=0
280 X1(T)=0
290 NEXT T
300 PRINT "DO YOU WISH TO SET TIME 1=YES 2=NO";
310 INPUT Z
320 IF Z=2 THEN 410
330 PRINT "ENTER THREE DIGIT DAY OF YEAR";
340 INPUT D$
350 PRINT "ENTER HOUR IN 24 HR FORMAT";
360 INPUT H$
370 PRINT "ENTER MINUTE 00 TO 59";
380 INPUT M$
390 PRINT @24:"003S",D$,H$,M$,"00S"
400 PRINT @24:"00M"
410 PRINT @24:"@03"
```

```
420 INPUT @24:A$
430 PRINT A$
440 PRINT @24:"@0H"
450 PRINT "DO YOU WISH TO INIT WATER METER 1=YES 2=NO"
460 INPUT T
470 IF T=1 THEN 490
480 IF T=2 THEN 750
490 REM THIS PORTION WILL ALLOW FOR THE READING OF THE
500 REM FIRST VALUE FOR THE WATER METER INTERFACE
510 REM FIRST GET D/A VOLTAGE
520 PRINT @24:"@001"
530 PRINT @24:"@012"
540 REM 400 SETS RANGE TO 31.00 VOLTS
550 PRINT @24:"@01I"
560 REM 420 TAKES READING
570 INPUT @24:Q
580 PRINT @24:"@0H"
590 PRINT @24:"@002"
600 PRINT @24:"@01I"
610 INPUT @24:R
620 PRINT @24:"@0H"
630 A=R/19.2
640 B=Q*19.2/R
650 J=INT(10*B)
660 K=10*B-J
670 IF K<0.25 THEN 730
680 IF K>0.75 THEN 710
690 K=0.5
700 GO TO 740
710 K=1
720 GO TO 740
730 K=0
740 C=(J+K)*10
750 REM 500 THRU 610 ARE FROM WATER METER SUBROUT (140-230)
760 PRINT @24:"@03"
```

```
770 INPUT @24:A
780 IF A/100=INT(A/100) THEN 810
790 PRINT @24:"@0H"
800 GO TO 760
810 PRINT @24:"@0N"
820 REM GO    TO ONE MIN TASKS ALSO INCR 10 MIN &  HR CTRS
830 GOSUB 880
840 REM HERE IS WHERE WE RETURN,CHECK MIN,HR,24HR CTR
850 PRINT A;
860 GO TO 760
870 REM START OF ONE MINUTE TASKS
880 LET L=L+1
890 LET M=M+1
900 LET N=N+1
920 REM HERE IS WHERE WE BRANCH AT THE HOUR
930 REM L,M,N ARE 10 MIN 1HR AND 24 HR CTRS RESPECTIVELY
940 PRINT @24:"@022"
950 PRINT @24:"@003"
960 PRINT @24:" @02I"
970 INPUT @24:P
980 PRINT @24:"@0H"
990 PRINT "P=";P
1000 IF P>2.5 THEN 1020
1010 GO TO 1040
1020 F=F+1
1030 REM P IS THE PUMP STATUS,AN IF/THEN STATEMENT WILL BE USED
1040 REM TO SEE IF PUMP IS ON OR OFF
1050 PRINT @24:"@004"
1060 PRINT @24:"@02I"
1070 INPUT @24:E
1080 PRINT @24:"@0H"
1090 PRINT "E=";E;
1100 IF E>2.5 THEN 1120
1110 GO TO 1130
1120 G=G+1
```

```
1130 REM E IS HEATER STATUS
1140 PRINT @24:"@@10"
1150 FOR T=1 TO 6
1160 PRINT @24:"@@@",T
1170 PRINT @24:"@@11"
1180 INPUT @24:W
1190 PRINT @24:"@@H"
1200 U(T)=W
1210 PRINT "U";T;"=";U(T)
1220 NEXT T
1230 FOR T=1 TO 5
1240 X(T)=U(T+1)-U(T)+X(T)
1250 PRINT "X";T;"=";X(T)
1260 REM IT MAY BE NECESSARY TO REASSIGN T COUP TO GET PROPER DIFF
1270 NEXT T
1280 REM REMEMBER TO MULT BY T COUP CONV FACTOR
1290 PRINT @24:"@@@7"
1300 PRINT @24:"@@11"
1310 INPUT @24:S
1320 PRINT @24:"@@H"
1330 PRINT "S=";S
1340 REM S IS THE IN SOL READING CH 7 DVM SLOT 1
1345 S1=S1+S
1350 REM PRINT S AND PRINT UT ARE FOR DEBUGING
1355 IF INT(M/60)=1 THEN 1370
1360 RETURN
1370 M=0
1380 PRINT "HOUR HAS PASSED"
1390 REM THIS STARTS 1 HR TASKS
1400 REM 1 HR TASKS INSERTED BEFORE NEXT GOTO STATEMENT
1410 PRINT "ONTIME OF HTR FOR LAST HR=";G/60;"HR"
1420 PRINT "ONTIME OF PUMP FOR LAST HR=";F/60;"HR"
1430 F1=F1+F
1440 G1=G1+G
1450 G=0
```

```
1460 F=0
1470 FOR T=1 TO 5
1480 PRINT "AVG'ED TEMP DIFF ACROSS";T;"AND";T+1;"=";X(T)/60;
1490 NEXT T
1500 FOR T=1 TO 5
1510 X1(T)=X1(T)+X(T)
1520 X(T)=0
1530 NEXT T
1540 REM HERE WE SAVE 24 HR VAR & ZERO OUT PREVIOUS HR
1550 REM H20 ROUT STARTS HERE
1560 PRINT @24:"@001"
1570 PRINT @24:"@012"
1580 PRINT @24:"@01I"
1590 INPUT @24:Q
1600 PRINT @24:"@0H"
1610 PRINT @24:"@002"
1620 PRINT @24:"@01I"
1630 INPUT @24:R
1640 PRINT @24:"@0H"
1650 B=Q*19.2/R
1660 K=10*B-INT(10*B)
1670 IF K<0.25 THEN 1730
1680 IF K>0.75 THEN 1710
1690 K=0.5
1700 GO TO 1740
1710 K=1
1720 GO TO 1740
1730 K=0
1740 D=(J+K)*10
1750 REM
1760 Y=D-C
1770 IF Y<0 THEN 1800
1780 V=Y*20
1790 GO TO 1810
1800 V=(12.75-C)*20+D*20+1
```

```
1 REM NEW N20 SUBROUTINE
2 REM D TO A VOLTAGE HAS 2 COMPONENTS
3 REM USE VAR V3>V8
4 REM READ VHIGH=Q1
5 REM READ VLOW=Q2
6 REM READ VHIGH=Q3
7 PRINT @24:"@002"
8 PRINT @24:"@022"
9 PRINT @24:"@02I"
10 INPUT @24:Q1
11 PRINT @24:"@0H"
12 PRINT @24:"@001"
13 PRINT @24:"@02I"
14 INPUT @24:Q2
15 PRINT @24:"@0H"
16 PRINT @24:"@002"
17 PRINT @24:"@02I"
18 INPUT @24:Q3
19 PRINT @24:"@0H"
20 IF Q3-Q1>0.25 THEN 4
21 J1=INT(Q1)
22 K1=Q1-J1
23 IF K1>0.75 THEN 27
24 IF K1<0.25 THEN 29
25 K1=0.5
26 GO TO 30
27 K1=1
28 GO TO 30
29 K1=0
30 Q1=J1+K1
31 J2=INT(Q2)
32 K2=Q2-J2
33 IF K2>0.75 THEN 37
34 IF K2<0.25 THEN 39
```

```
35 K2=0.5
36 GO TO 40
37 K2=1
38 GO TO 40
39 K2=0
40 Q2=J2+K2
41 V3=Q2+16*Q1
42 REM AT THIS POINT V3 IS THE TOTAL D/A QUANTIZED VOLTAGE
43 REM FOR INITIALZATION V4= V3
44 IF V3=>V4 THEN 47
45 V=2*V3+(V4-127.5)*2+1
46 GO TO 48
47 V=(V3-V4)*2
48 V4=V3
```

```
100 PRINT @41,11:1
110 PRINT @37,26:1
120 PRINT @41:
130 PRINT @41:"
140 PRINT @41:"      DOMESTIC HOT WATER"                                    ";
150 PRINT @41:"                                                  COMPARISON OF ";
160 PRINT @41:"SOLAR VS. ELECTRIC ENERGY USAGE ON ";D;"-";N;"-";M
170 PRI @41:"                 ------------------------------------------";"
180 PRINT @41:"-----"----------------------------------------------";
190 PRINT @41:"-----
200 PRINT @41:"                  ";
210 PRINT @37,26:0
220 PRINT @41:"|";"       |";"                        BTU'S COLLECTED      ";
230 PRINT @37,26:0
240 PRINT @41:"          || INSO- | ELEC. | WATER |   %   | TOTAL |"
250 PRI @41:"                    ----------------------------------";"
260 PRINT @37,26:1
270 PRINT @41:"---------------"
280 PRINT @41:"      ";
290 PRI @41:"       |      |     GRUMMAN     |   HONEYCOMB    |     ";
300 PRINT @37,26:0
310 PRINT @41:"  GE       ||      |      |      |      |      | "
320 PRINT @41:"     ";
330 PRI @41:"
340 PRINT @37,26:1                 ----------------------------------";"
350 PRINT @41:"---------- LATION   ENERGY                BTU          "
360 PRINT @41:"           | TIME  |      |      |      |      |      |";
370 PRINT @41:"     |     |    |  ||      |      |      |      |      ";
380 PRINT @41:"BY   |     |"
390 PRINT @41:"           |      | BTU | BTU |  % | BTU | BTU |";
400 PRINT @37,26:0
410 PRINT @41:"  % | BTU | BTU |  % || BTU   | BTU'S | GAL | 80°";
420 PRINT @41:"LAR | BTU'S |"
430 PRINT @41:"                                  ---          --- ";
```

115

116

```
440 PRINT @37,26:1
450 PRINT @41:"
460 PRINT @41:"                    ---                 ---"
470 PRINT @41:"    |       | SF    |     |  SF   |     |     | SF  |  SF  |"
480 PRINT @41:"    |       |       |"    |       |     |     |     |      |"
490 PRINT @41:"                    |-------|-----|-----|----|-----|-----|-"
500 PRINT @41:"---|-----|-----|----||-------|-------|-------|---"
510 PRINT @37,26:0
520 PRINT @41:"----|-------|"
530 PRINT @41:"
540 PRINT @37,26:1                 ------------------------------------"
550 PRINT @41:"
560 PRINT @41:"----------"----------------------------------"
570 FOR I=1 TO 24 ----------
580 PRINT @37,26:0
590 PRINT @41:"
600 PRINT @41:"    |     |     |     |     |     |     |     |     |     |"
610 PRINT @41:"    |     |     |     |"    |     |     |     |     |     |"
620 PRINT @37,26:1
630 PRINT @41:"
640 PRINT @41:"                    ------------------------------------"
650 PRINT @41:"----------"----------------------------------"
660 NEXT I ----------
670 PRINT @41:"
680 PRINT @41:"                    ------------------------------------"
690 PRINT @41:"----------"----------------------------------"
700 PRINT @37,26:0
710 PRINT @37,26:0
720 PRINT @41:"
730 PRINT @41:"                    | TOTAL |     |     |     |     |     |"
740 PRINT @41:"    |     |     |     |     |     |     |     |     |     |"
750 PRINT @41:"    |     |     |     |"    |     |     |     |     |     |"
760 PRINT @41:"                    ------------------------------------"
770 PRINT @41:"----------"----------------------------------"
780 FOR I=1 TO 17 ----------
```

```
790 PRINT @37,26:1
800 PRINT @41:" "
810 NEXT I
820 PRINT @37,26:0
830 PRINT @41,11:0
```

APPENDIX

TEACHING THE PRINCIPLES OF SOLAR ENERGY IN THE UNDERGRADUATE ENGINEERING LABORATORY

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Lupton Hall
Farmingdale, N.Y. 11735

INTRODUCTION

In the aftermath of the recent accident at the Three Mile Island power plant there have been charges levelled by the opponents of nuclear power about a "cover-up" and "lies" to which the American public has been subjected relative to the dangers of nuclear energy. Even those who assume a more charitable attitude to the proponents of nuclear power admit that the nuclear industry has at least indulged in some wishful thinking concerning the problems of nuclear safety.

Solar energy has often been presented as the "good guy" alternative to nuclear energy, and this tendency has intensified considerably since the Three Mile Island incident. Unfortunately, some very vocal proponents of solar energy have been carried away by the new interest and support that they have suddenly gained, and have responded by indulging in their own brand of wishful thinking regarding the unlimited virtues and potential of solar as an almost overnight replacement for nuclear.

The application of solar energy to the areas of heating, cooling and power generation on a scale that would make a significant contribution to the needs of our nation involves a tremendous technological effort, and a technologically difficult one, at that. After many years of work involving thousands of participants in our country alone, we are just scratching the surface in the solar field; and large scale, economically feasible solutions are not around the corner. There is still a long hard road ahead, and let us not make it more difficult for ourselves by over-selling our position, and damaging our credibility.

IMPORTANCE OF TRAINING

One of the important tasks that we face in the Solar Energy field today is the training of engineers and technicians, including instruction in the areas of both theory and lab. The purpose of this paper is to focus in on three experimental sequences relating to the teaching of solar heating and cooli

CHOOSING EXPERIMENTS FOR THE SOLAR LAB

There are several valid approaches that ma be used to teach the principles and design solar powered heating and cooling systems the under-graduate engineering laboratory. These include:

1. Evaluation of collector efficiencies different types of collectors, collect angles, time of day, season, latitude, etc.

2. Construction and installation of syste including structural methods, prevent of freezing, corrosion protection, co requirements, etc.

3. Investigation of energy relationships different types of systems.

4. Etc.

Of the above, the area of energy relation ships was chosen for our laboratory.

SELECTION OF INSTRUCTIONAL SYSTEMS FOR LA

The selection of systems for our lab was based on the following criteria:

1. Which application has the greatest number of installations at the presen time?

2. Which is the simplest application for space heating?

3. Which system utilizes a refrigeration cycle?

Having thus made our choice of the types systems to be used, the task at hand was design and install instructional equipmen that would best highlight the features of systems selected.

The following sections of this paper wil

deal with the circuiting and operation of the systems designed. In the case of the Solar Assisted Heat Pump, a typical set of computer-processed input data and output results will be presented.

ORIGIN TITLE ON FIRST PAGE HERE
CENTER BLACKBOARD HORIZONTALLY

DOMESTIC HOT WATER SYSTEM

The circuit for the solar-heated domestic hot water system as shown in Figure (1) is conventional, but with the following exceptions:

(a) The different types of collectors, a Grumman flat plate residential type, a Universal Industries honeycomb type, and a G.E. concentrating type, are connected in a series loop.

(b) A Tektronix 4051 computer and a computer Data System Data Logger are interfaced with the system to automatically monitor, collect, process and issue a daily printed report on the solar insolation available, the comparative efficiencies of the three different types of collectors, and the relationship of conventional and solar energy utilized on that particular day.

(c) A solenoid operated dump valve, controlled by a time clock is employed to supplement the limited use of hot water in the lab to make it equivalent to the typical use of hot water in a residence.

The main instructional objectives of this experiment are:

(a) To analyze and evaluate the savings in conventional energy (if any) in respect to the total solar insolation for any given day.

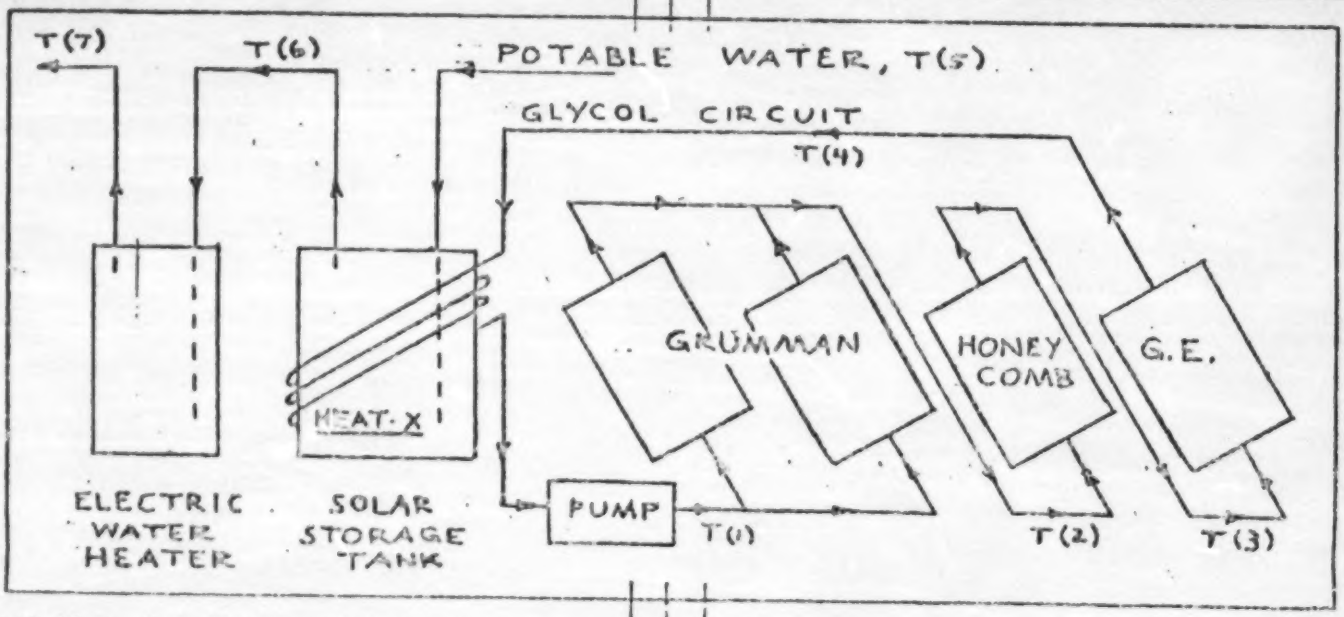
(b) To relate the savings in conventional energy to the cost of the installation.

(c) To compare the effectiveness of the three types of collectors.

(d) To gain experience in setting up and using automated data collection and processing.

AIR/AIR SOLAR SPACE HEATING

The circuit for the Air/Air Solar Space Heating Simulator is shown in Figure (2). This system varies "solar insolation" by using an autotransformer controlled heater, and varies the "heating load" by means of a percentage timer, (instead of a thermostat). The system is built to the approximate scale of 1:100. Fan "A" circulates air between the "collector" and the rock storage. Fan "B" draws air through the rock storage and electric furnace, thus supplying heated air to the space in need of heat. The electric furnace is energized only if the heat picked up in the rock storage is insufficient to raise the temperature of the supply air to at least 110F.



Description of Automatic Data Sensors:

T(1): Glycol entering first collector, °F
T(2): Glycol entering second collector, °F
T(3): Glycol entering third collector, °F
( ): Glycol entering heat exchanger, °F
T(5): Tap water entering solar tank, °F
T(6): Water entering electric heater, °F
Glycol flow rate
Solar Insolation
Electric Power Consumed, Heater and Pump
Water quantity used in 24-hour period

FIGURE - 1 DOMESTIC HOT WATER SYSTEM CIRCUIT

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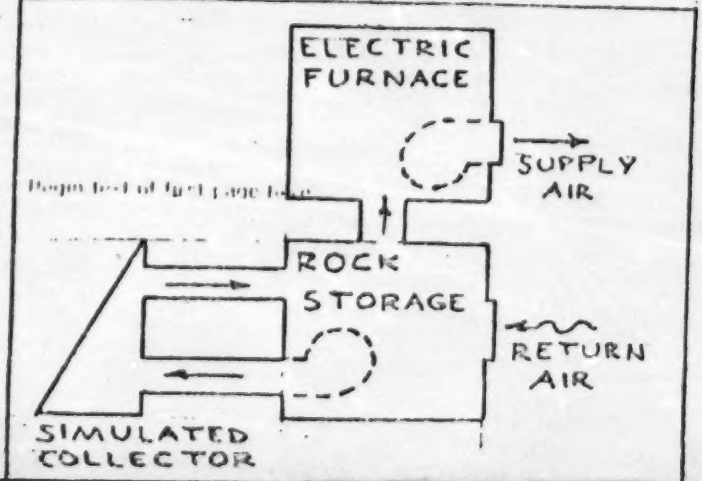
The main instructional objectives of this experiment are:

(a) To calculate and analyze the energy relationships between the solar and electrical energy used for heating.

(b) To gain insight in understanding the significance of the temperature at which solar energy is collected.



Since the sun shines only during the day, the heat pump only runs at night, and since the function of the system varies with the seasons, eight 3-way valves are employed to direct the chilled and heated water through the various sequences that are demanded by these operating modes. Space does not permit a complete description of these flow circuits and their features, but some of their highlights are as follows:

(a) Pump-I may function as the collector pump during a winter's day, the chille pump during a winter's night, and the condensing water pump during a summer' night.

(b) Pump-II circulates chilled water throu the fan coil in the summer, and heated water in the winter.

(c) The Solar Tank and Cold Tank operate a a single unit during the winter operation of the heat pump. (Note the ove flow line connecting the two tanks.)

SIMULATED COLLECTOR

FIGURE-2. AIR/AIR SOLAR SPACE HEATING CIRCUIT

SOLAR ASSISTED HEAT PUMP

The plumbing circuit for the Solar Assisted Heat Pump is shown in Figure (3). The dedicated heat pump employed in this system, (not shown in diagram), does not require a reversing valve, but produces hot and cold water simultaneously whenever it operates, by virtue of the fact that its condenser and evaporator are immersed in the hot and cold tanks, respectively. The system is designed to produce and store a sufficient quantity of both hot and cold water for a 24-hour period, although the heat pump itself operates only at night during the "off-peak" hours.

flow line connecting the two tanks.)

(d) Flow in unmarked lines can go in either direction.

(e) There are several back-up heating methods that can be combined with the circuit shown that would take advantage of off-peak power utilization.

(f) The system described utilizes three 100-gallon storage tanks, and is built to the approximate scale of 1:10 in relation to the requirements of a small home.

The instructional objectives of this experiment are similar to the ones stated for the previous ones described. Figure (4) and Figure (5) show sample data and computerized print-outs for the heating and cooling modes respectively.

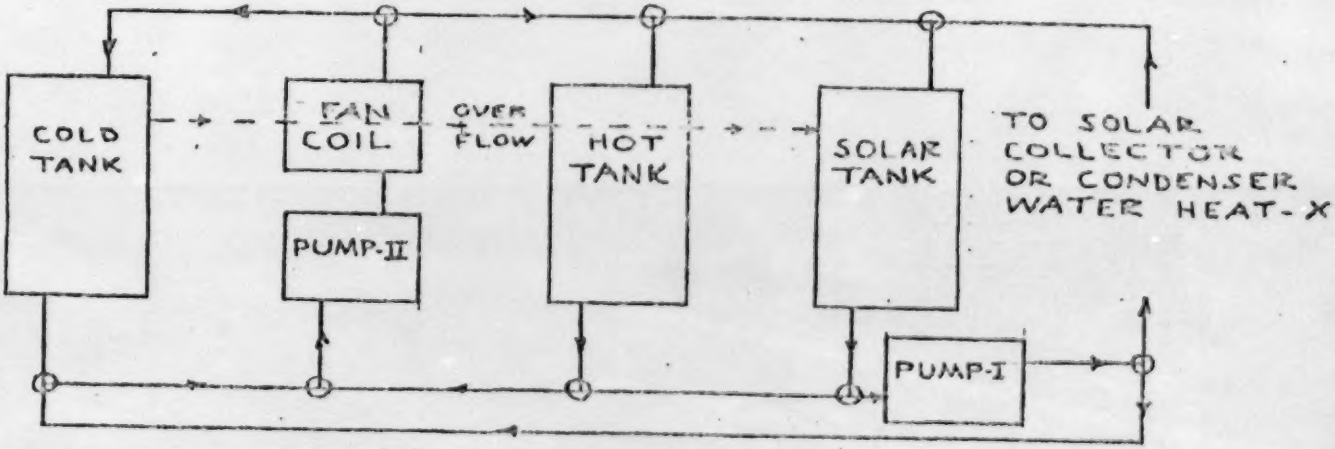
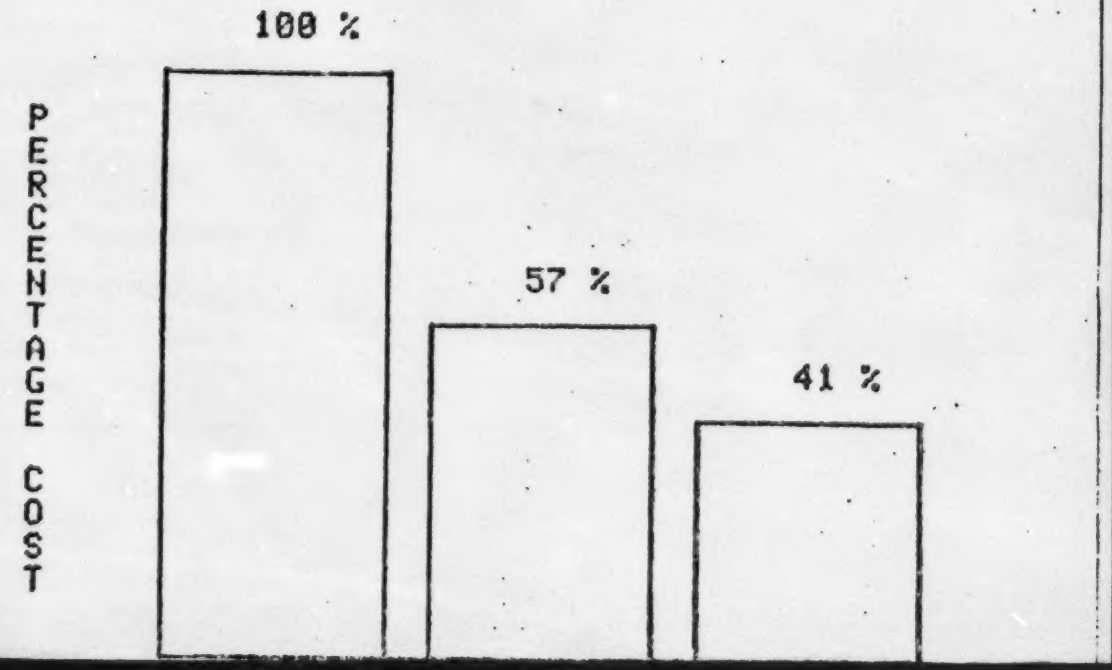


FIGURE-3. PLUMBING CIRCUIT FOR SOLAR-ASSISTED, OFF-PEAK POWER HEAT PUMP

COST COMPARISON OF HEATING SYSTEM USING STANDARD RESISTANCE HEAT, OFF-PEAK RESISTANCE HEAT AND SOLAR ASSISTED HEAT PUMP SYSTEM

FIGURE - 4



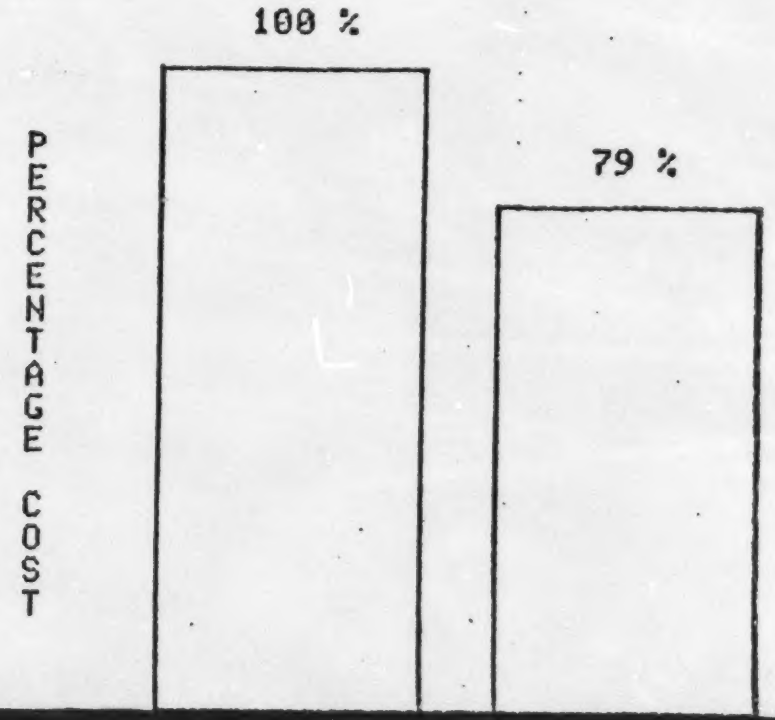
STANDARD RESISTANCE HEAT	OFF-PEAK RESISTANCE HEAT	OFF-PEAK HEAT PUMP

TEST DATA

WATER FLOW RATE, (lbs/hr),	M1 = 200
TANK CAPACITY, (lbs),	M2 = 800
ENTERING COIL TEMP, (F),	T1 = 120
LEAVING COIL TEMP, (F),	T2 = 100
INITIAL TANK TEMP, (F),	T3 = 120
FINAL TANK TEMP, (F),	T4 = 115
HOURS OF TEST,	H = 2
STANDARD ELECTRIC RATE, ($/KW-HR),	R9 = .06
OFF-PEAK ELECTRIC RATE, ($/KW-HR),	R8 = .02
PEAK ELECTRIC RATE, ($/KW-HR),	R7 = .10
WATTS INPUT TO HEAT PUMP,	W1 = 200
WATTS INPUT TO WATER CIRCULATOR,	W2 = 40
WATTS INPUT TO FAN,	W3 = 30

COST COMPARISON OF COOLING SYSTEM USING OFF-PEAK ELECTRICAL RATE FOR 8-HOURS, PLUS STORAGE, VS STANDARD ELECTRICAL RATE FOR 24-HOURS, WITHOUT STORAGE

FIGURE - 5



STANDARD RATE

OFF-PEAK RATE

(TEST DATA)

WATER FLOW RATE, (lbs/hr),	M3 = 200
COLD TANK CAPACITY, (lbs),	M6 = 800
ENTERING COIL TEMP, (F),	T5 = 40
LEAVING COIL TEMP, (F),	T6 = 50
INITIAL TANK TEMP, (F),	T7 = 40
FINAL TANK TEMP, (F),	T8 = 38
DURATION OF TEST, (hrs),	H5 = 2
HEAT PUMP WATTS,	W5 = 200
WATER PUMP WATTS,	W2 = 40
FAN WATTS,	W3 = 30
PEAK RATE, ($/KW-HR),	R7 = .10
OFF-PEAK RATE, ($/KW-HR),	R8 = .02
STANDARD RATE, ($/KW-HR),	R9 = .06